WADC TECHNICAL REPORT 54-51

AISI 98B40 COMPRESSOR WHEELS AND GEARS

J. E. ANDERSON
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AIRCRAFT GAS TURBINE DIVISION
GENERAL ELECTRIC COMPANY

FEBRUARY 1954

WRIGHT AIR DEVELOPMENT CENTER

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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Aircraft Gas Turbine Division, General Electric Company under USAF Contract AF 33(038)-30522. The contract was initiated under the research and development project identified by Research and Development Order No. R477-645 A, and was administered under the direction of the Metallurgy Research Branch, Wright Air Development Center, with Mr. James W. Poynter acting as project engineer.

The investigation was carried out as part of the work of the Critical Materials Section, J47 Project, Aircraft Gas Turbine Division, General Electric Company. A similar study also was conducted by the Critical Materials Section. The results of that work were reported in WADC Technical Report 53-60, AISI 98B40 in the Turbine Hub and Shaft Application.

ABSTRACT

The desire to minimize the use of critical materials suggests the application of AISI98B40, a boron steel, to jet engine components. Compressor wheels and gears represent promising applications. Manufacture of a quantity of wheels and gears indicates no unusual procedures or precautions are necessary for the processes concerned—forging and such types of machining as turning and broaching. A metallurgical investigation of the wheels concludes that the mechanical properties of wheels made of AISI98B40 are essentially equivalent to wheels made of 4340. A similar study of induction-hardened gears shows that AISI98B40 should be limited to gear applications requiring a case hardness not greater than 54 R_c, which is comparable to the hardness attainable with 4340. Completion of engine and dynamometer tests is required before any recommendations can be made concerning the use of AISI98B40 in the compressor wheel and gear applications now specifying AISI4340.

PUBLICATION REVIEW

This report has been reviewed and is approved.

For the Commander:

LESLIE B. WILLIAMS, Colonel, USAF
Chief, Aeronautical Research Laboratory
Directorate of Research

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I. INTRODUCTION

The extensive use of rich alloy steels has made the United States dependent on other nations as sources of the necessary alloying elements. In war, such sources of supply will not be dependable. Consequently, patriotic engineers are studying ways to reduce the need and find substitutes for rich alloy steels. One very important way is the use of small amounts of boron instead of relatively huge amounts of nickel and molybdenum to achieve a desired hardenability response. However, the successful application of boron bearing steels cannot be attained by the comparison of hardenability bands and the performance of standard metallurgical tests alone, but by confirming the results of such work with the experience of service testing and manufacturing parts made of the new steels. This has been the purpose of this investigation. A similar study concerned with the application of AISI 98B40 to the turbine hub and shaft design of the J47 jet engine has been completed and is described in WADC Technical Report 53-60. This report describes the application of AISI 98B40 to several compressor wheel and gear designs of the J47 engine.

II. POSSIBLE APPLICATIONS OF AISI 98B40 TO JET ENGINES

In addition to the turbine hub and shaft, the compressor wheels, particularly in the aft stages, and the medium and lightly loaded gears of the accessory drives are the possible applications of AISI 98B40 to jet engine designs. The material now used for such parts is AISI 4340, a rich alloy steel with exceptionally good hardenability.

A knowledge of what the shapes of these parts are like and what properties are required primarily determines the selection of a material. Some illustrative information is presented to describe the geometry and stresses of the parts that were investigated. An assembled jet engine compressor rotor is shown in Fig. 1. The compressor blades are assembled to the wheels by a dovetail connection. A blade and wheel assembly is termed a compressor stage. The stages are secured by bolting. Alignment is assured by the use of a curvic coupling. In Figs. 2 and 3, the forward and aft faces of a first and twelfth stage compressor wheel are shown. The annular ring of gear tooth like projections surrounding the bolt holes is the curvic coupling. Intermediate stages are similar in appearance to Fig. 4. Note the absence of a

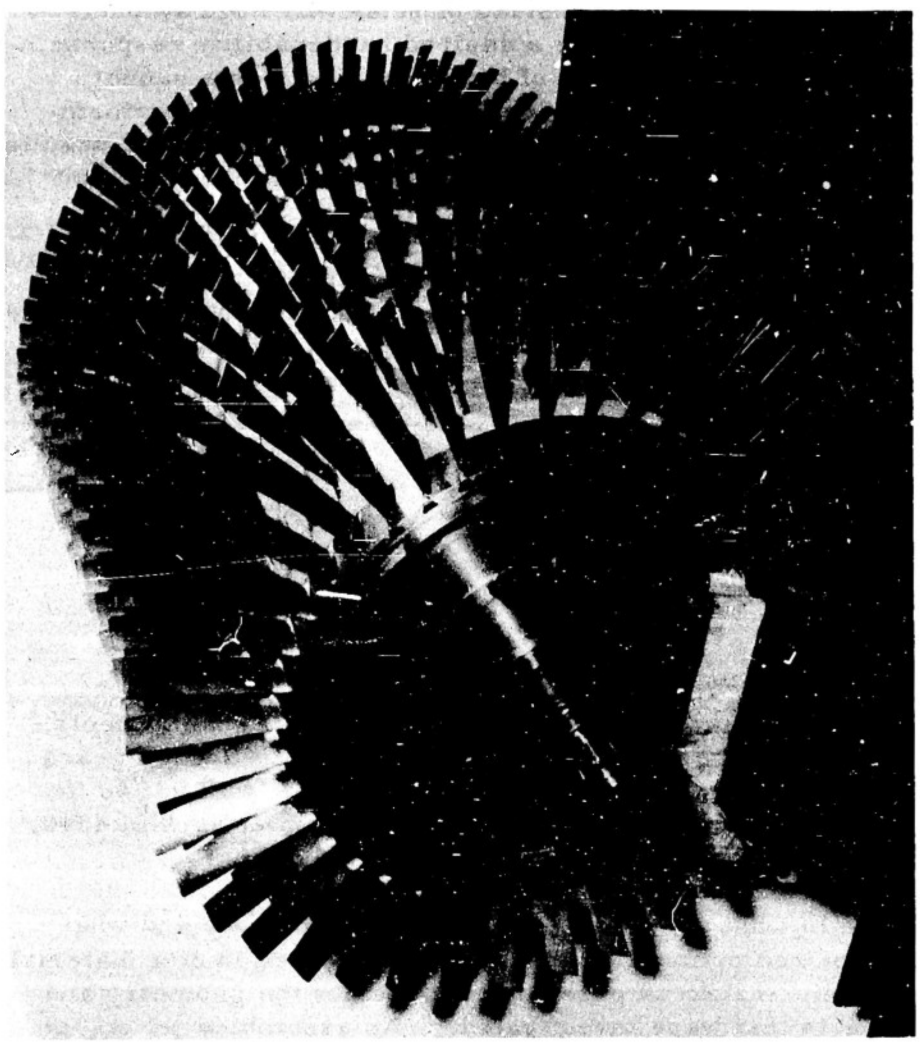
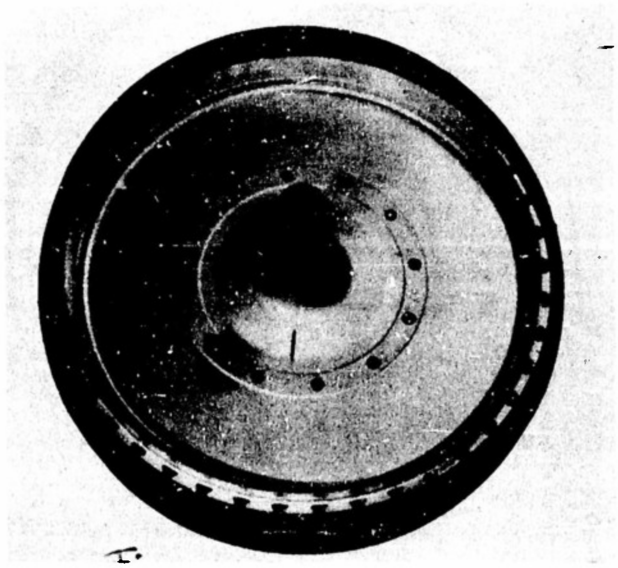


Fig. 1

Jet Engine Compressor Rotor
First Stage In Foreground



Jet Engine First Stage Compressor Wheel
Forward View

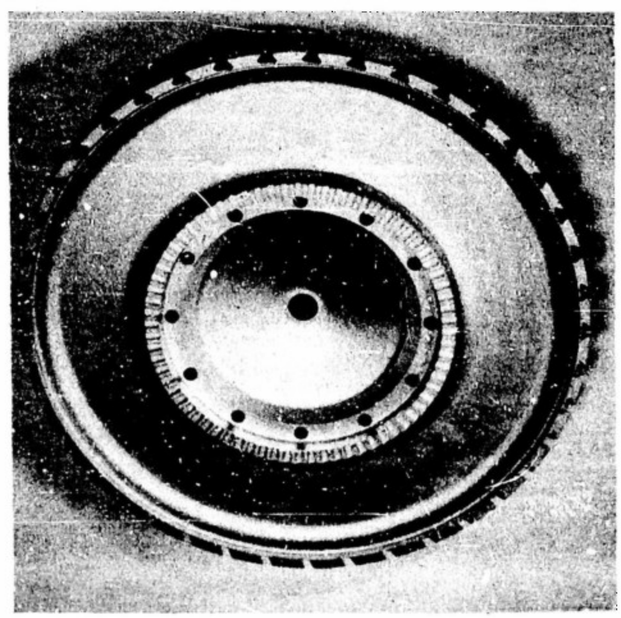
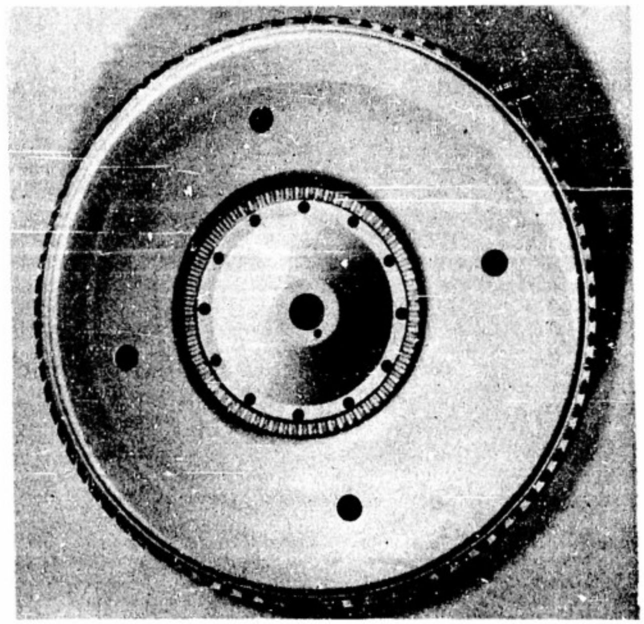


Fig. 2

Jet Engine First Stage Compressor Wheel
Aft View



Jet Engine Twelfth Stage Compressor Wheel
Forward View

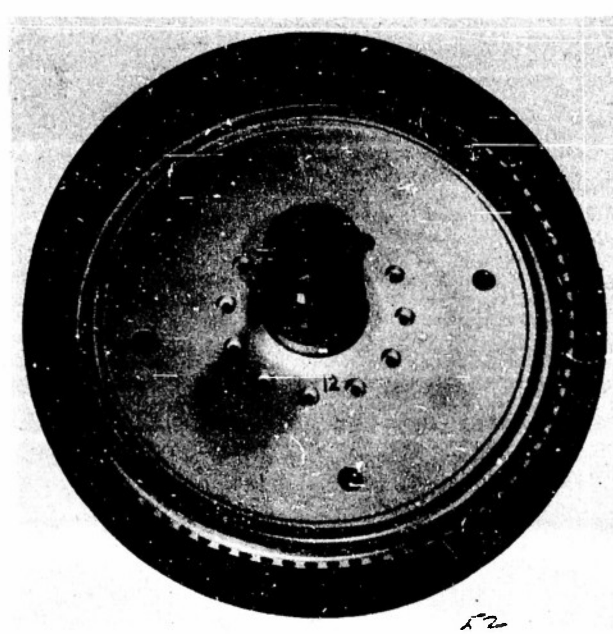


Fig. 3

Jet Engine Twelfth Stage Compressor Wheel
Aft View

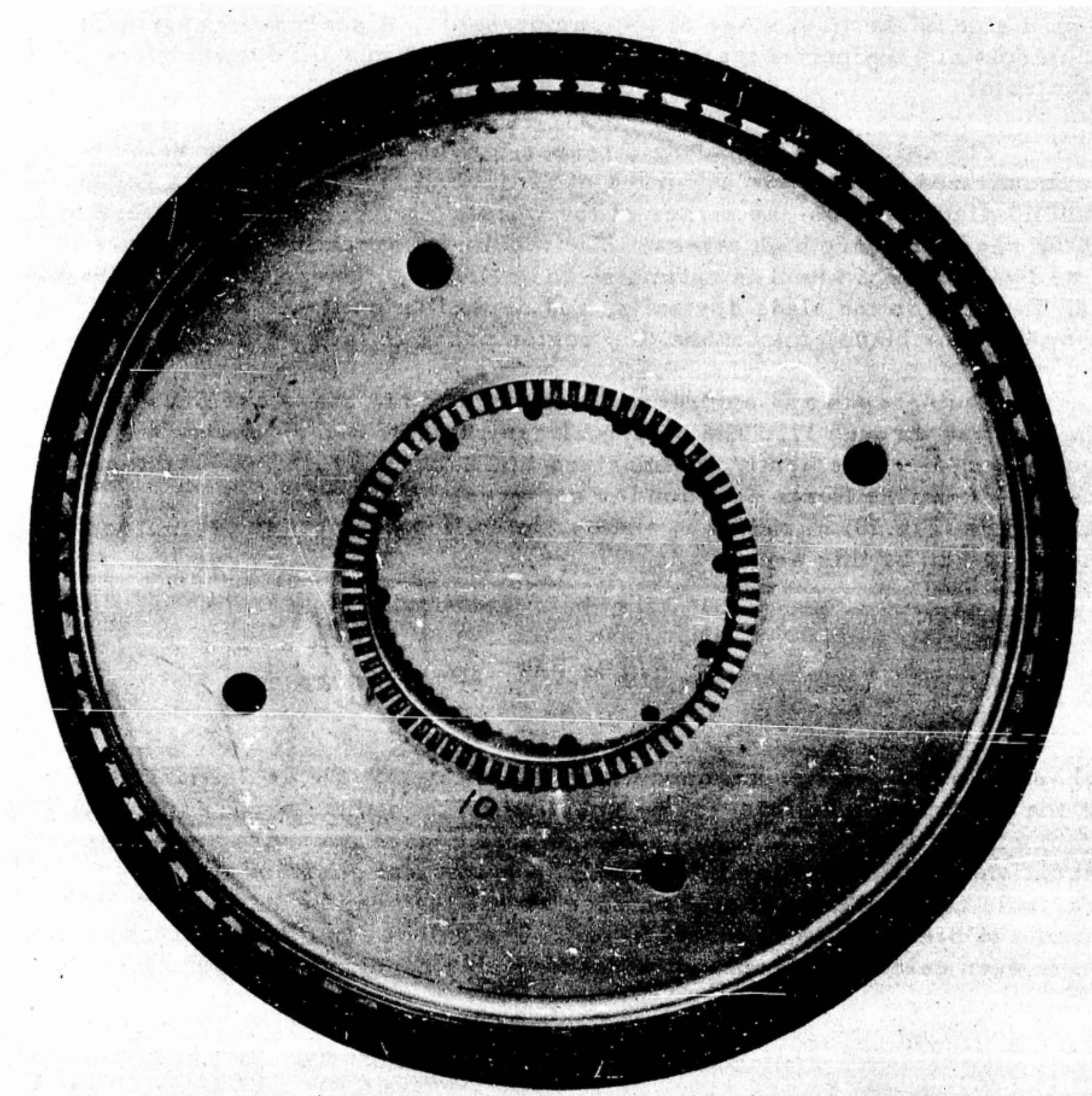


Fig. 4

Jet Engine Tenth Stage Compressor Wheel

center shaft. The engineering drawings of the compressor wheels are presented as Figs. 5 through 8. It will be noted that the first stage of of this compressor is made of steel, AISI 4340. This results from the use of high temperature, high pressure air to balance the forward thrust of the rotor assembly. Air is piped from the twelfth stage to the forward side of the first stage of the compressor. A sealing arrangement controls and maintains the pressure directed against the forward face of the rotor.

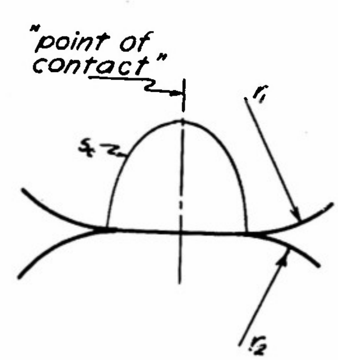
The calculated operating stresses for the compressor wheels are summarized in the form of curves of radial and tangential stress versus radial distance from the center of the wheel, Fig. 9. The hub is seen to be a region of very high stress. The maximum operating temperature of the twelfth stage wheel is estimated to be 450°F. Severe stress concentrations exist in the blade dovetails, and depending on the fit with the compressor blade, may make this region prone to fatigue failure.

Photographs and engineering drawings of the gears are presented in Figs. 10 through 17. The strength requirements and geometry of the gear teeth is conveniently summarized in Table 1. The term K factor is derived from the Hertz equation for compressive stress. For two cylinders (Fig. 18) of radius r_1 and r_2, in rolling contact, the compressive stress given by this equation is

$$S_c^2 = .35 \frac{W}{F} \left[\frac{\frac{1}{r_1} + \frac{1}{r_2}}{\frac{1}{E_1} + \frac{1}{E_2}} \right]$$

where E_1 and E_2 represents modulus of elasticity, W the radial load, and F the width of the cylinders. By substituting the values obtained from the geometry of an involute gear tooth with a 20 degree pressure angle, the equation can be rewritten in terms of a numerical constant and a variable called the K factor. Surface stress then can be interpreted in terms of pressure angle and K factor. The values for the root stress have been calculated from empirical formulae considered proprietary.

Fig. 18
Herts Compressive Stress



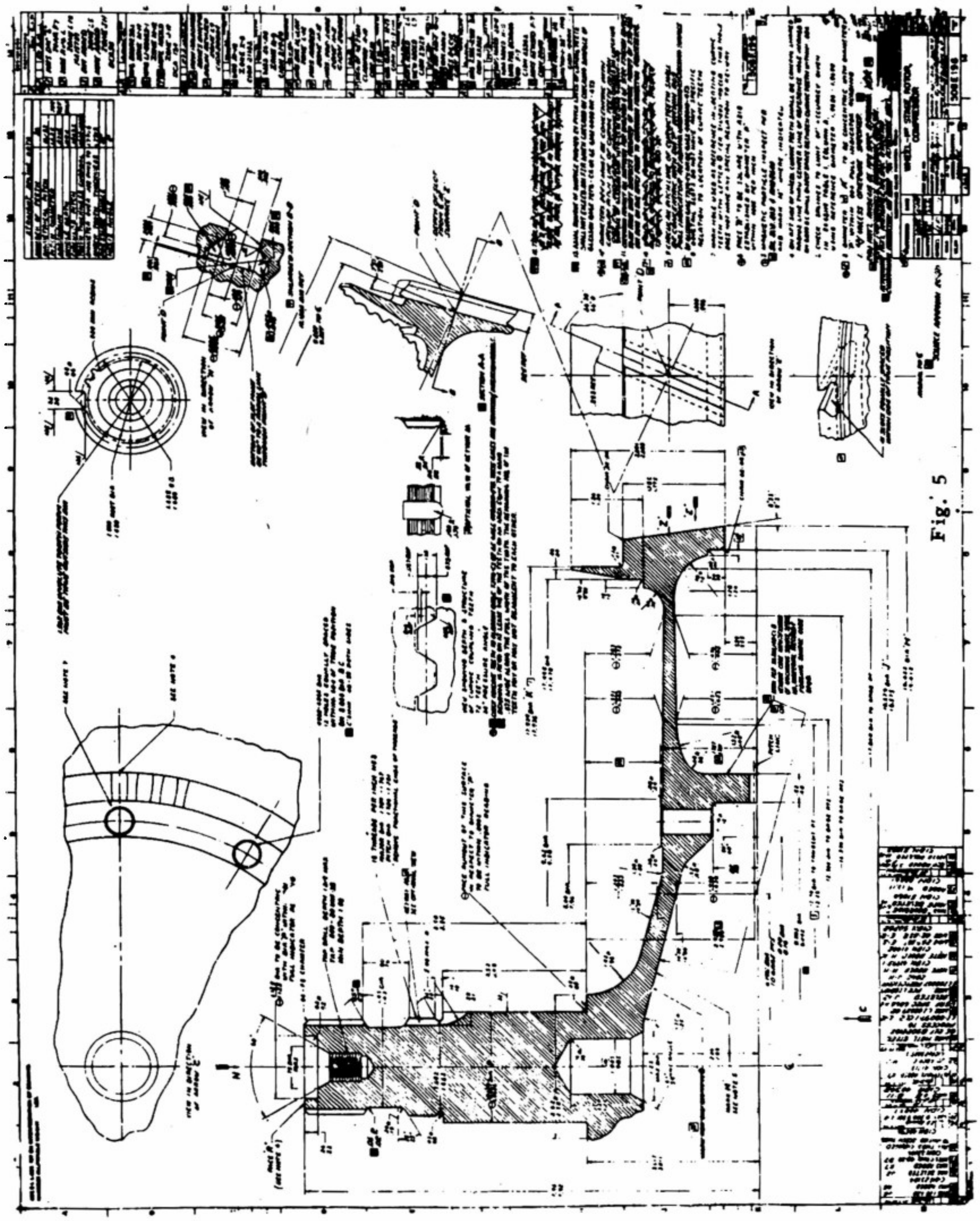


Fig. 5

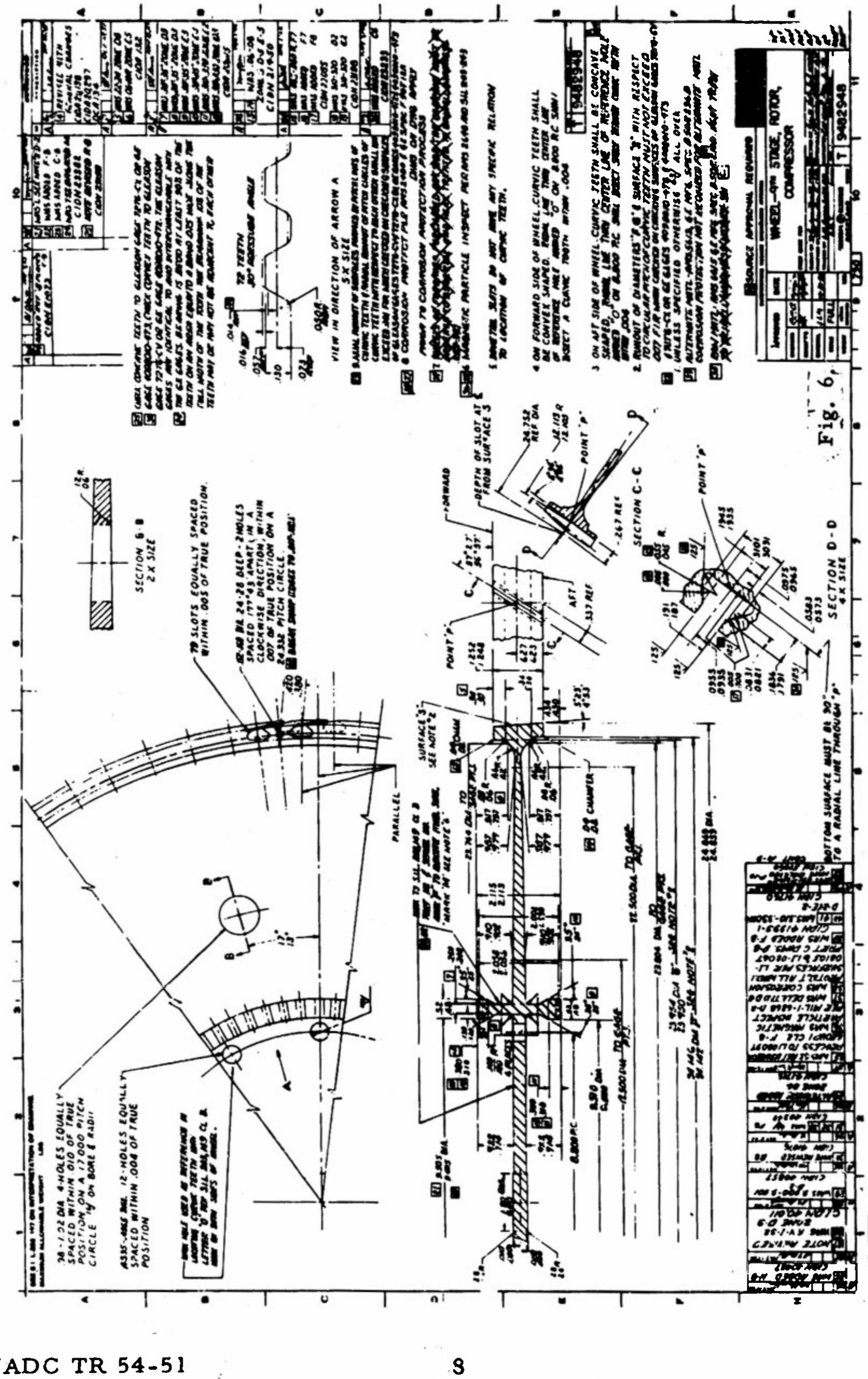


Fig. 6

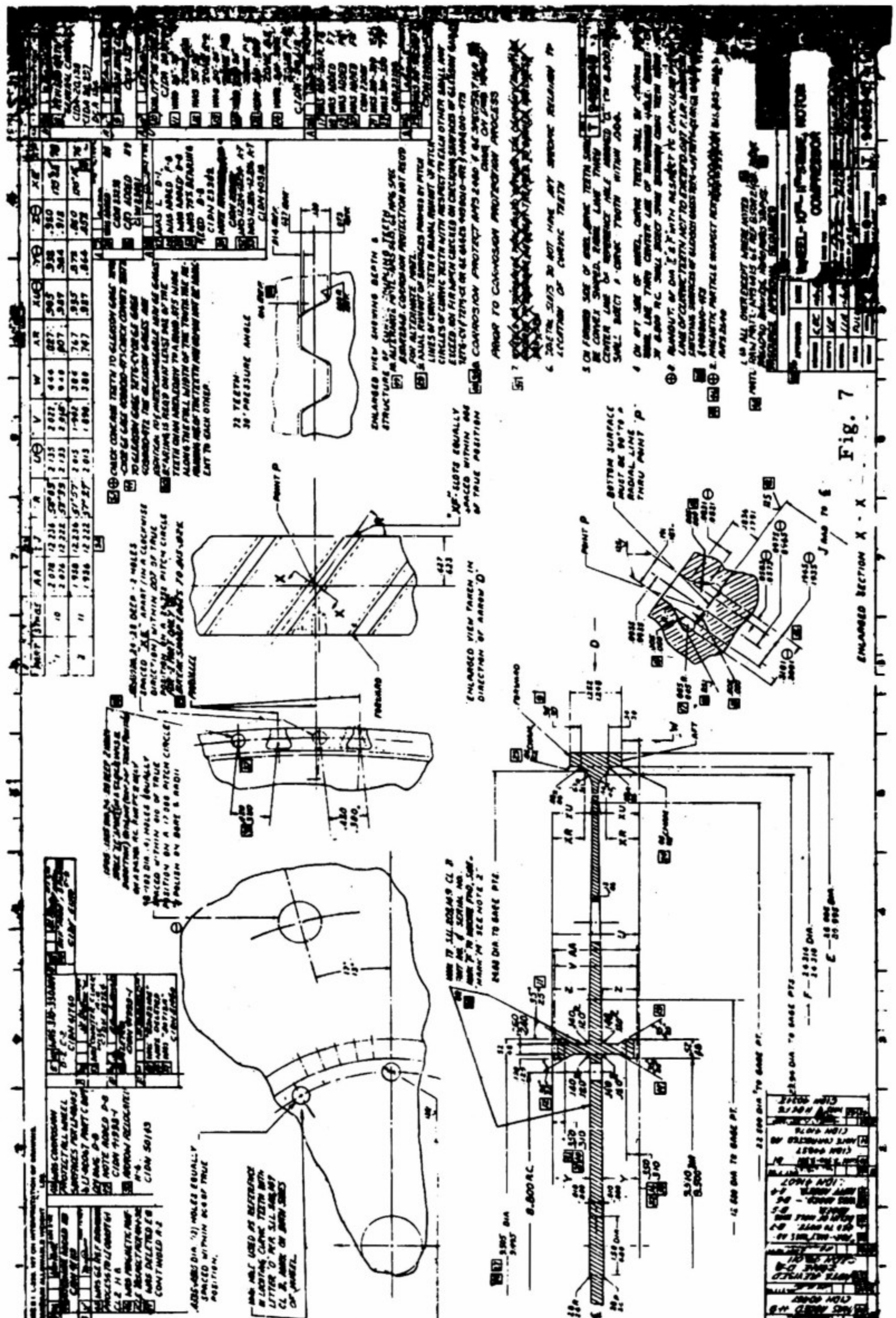


Fig. 7

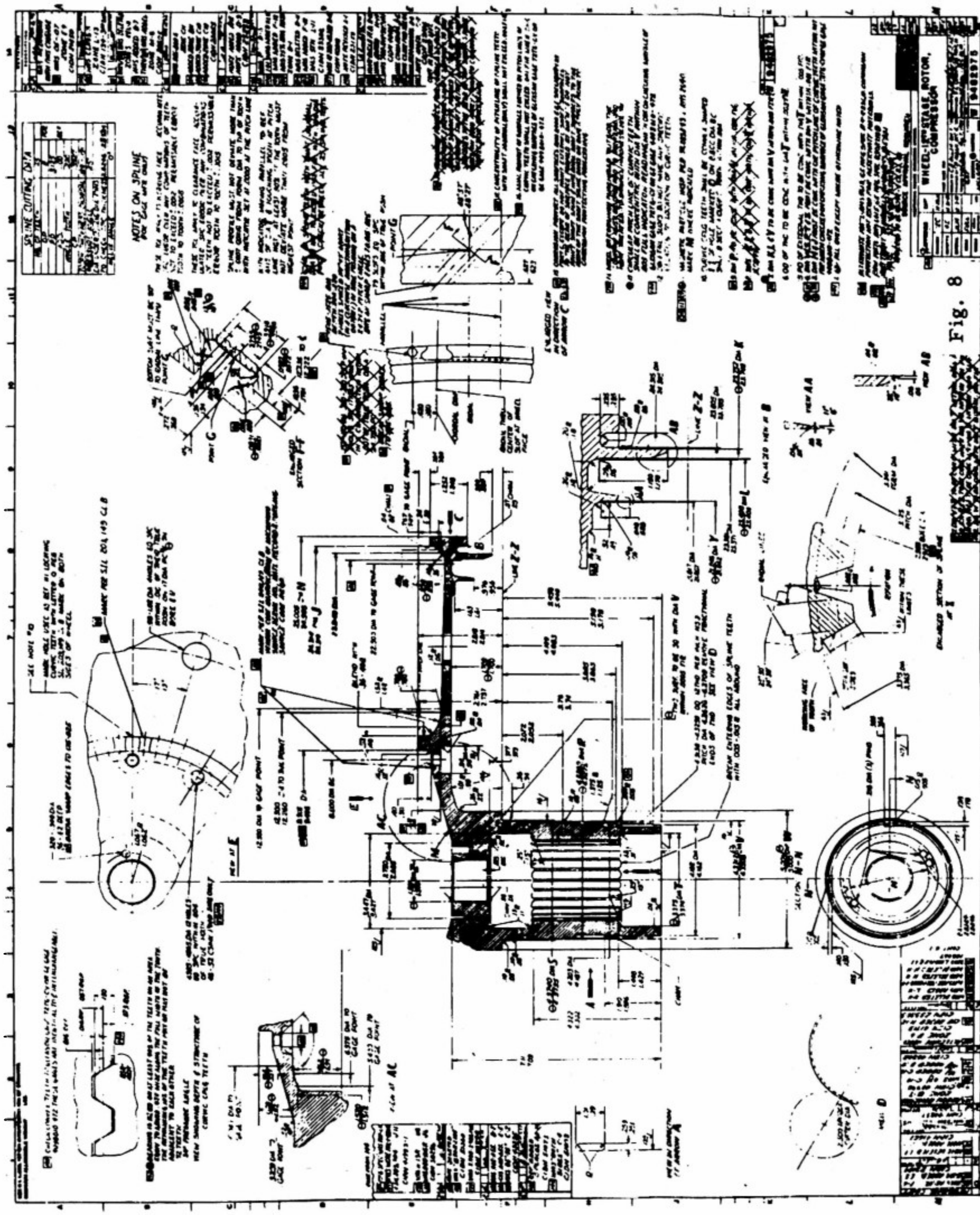


Fig. 8

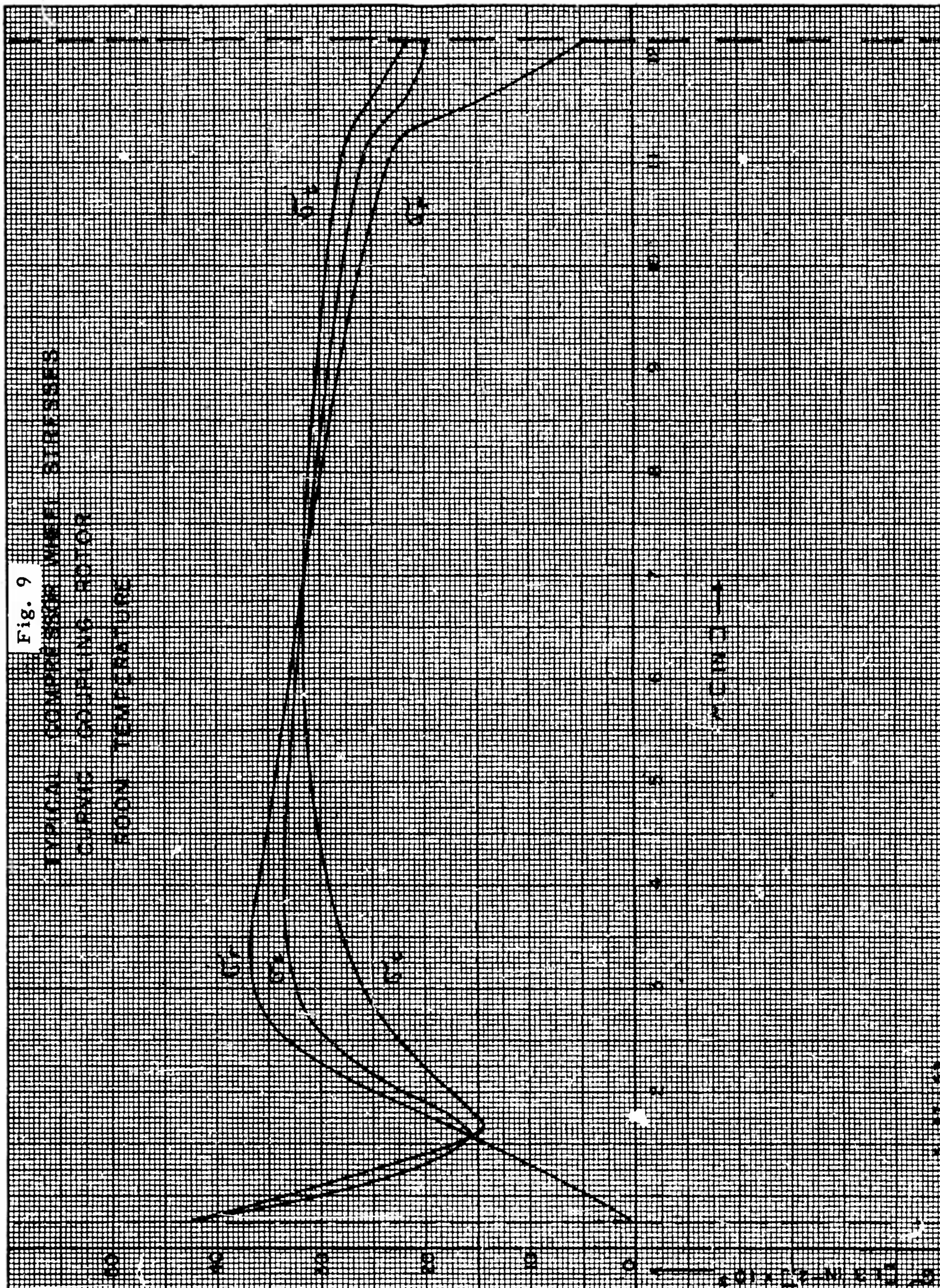

TYPICAL COMPRESSOR WHEEL STRESSES
CURTIS COUPLING ROTOR
ROOM TEMPERATURE

Fig. 9

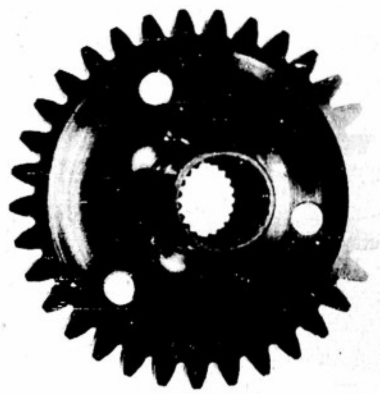


Fig. 10
Gear, 9493013

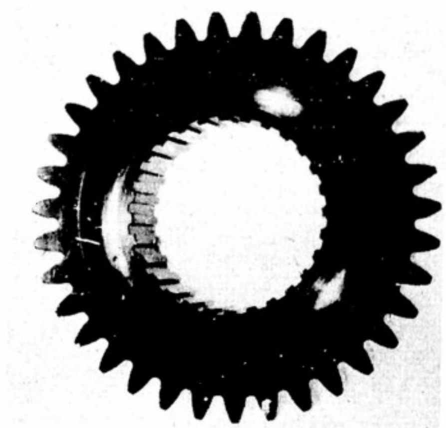


Fig. 11
Gear, 8992877

Fig. 12
Gear, '9493017

Fig. 13
Gear, 9493008

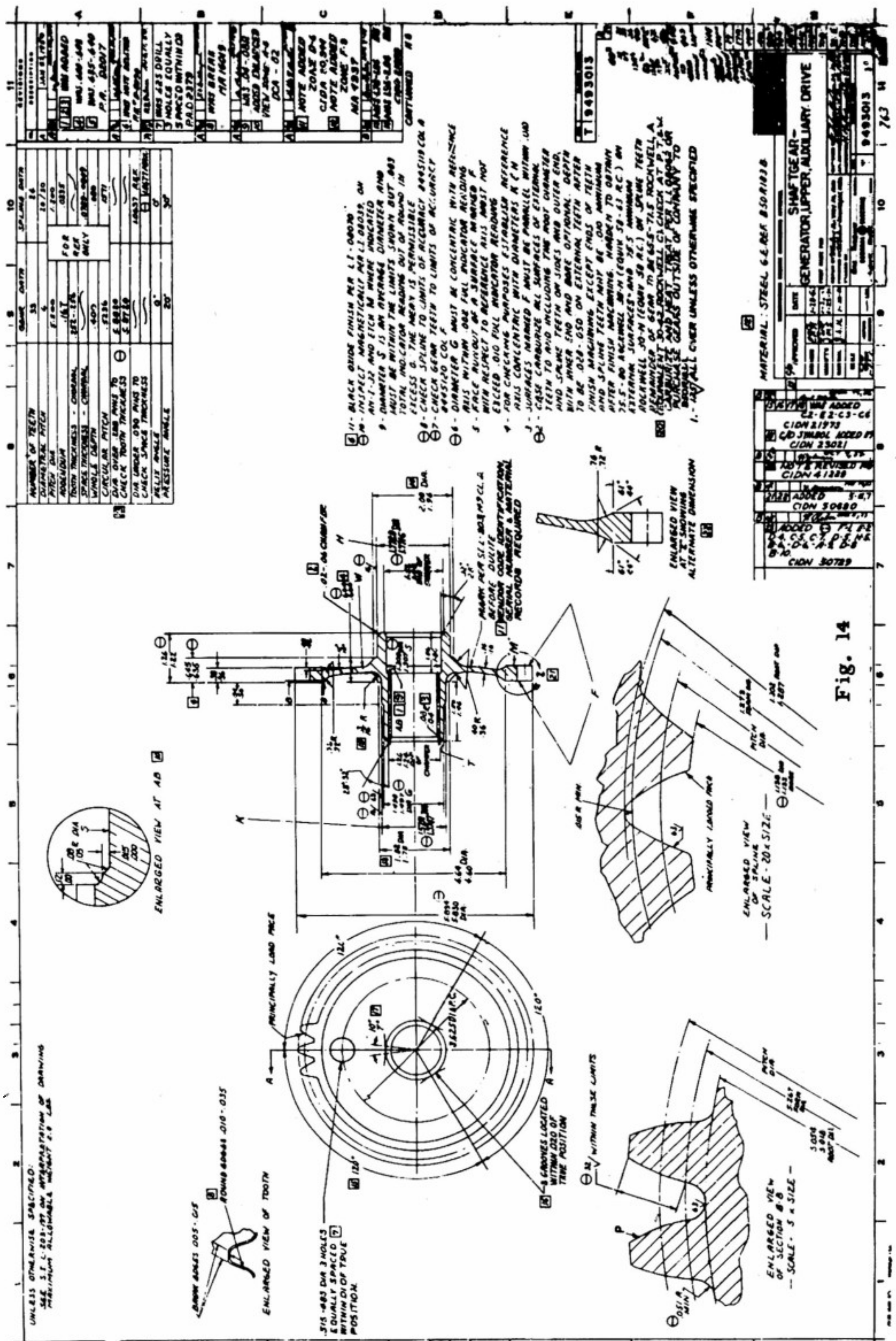


Fig. 14

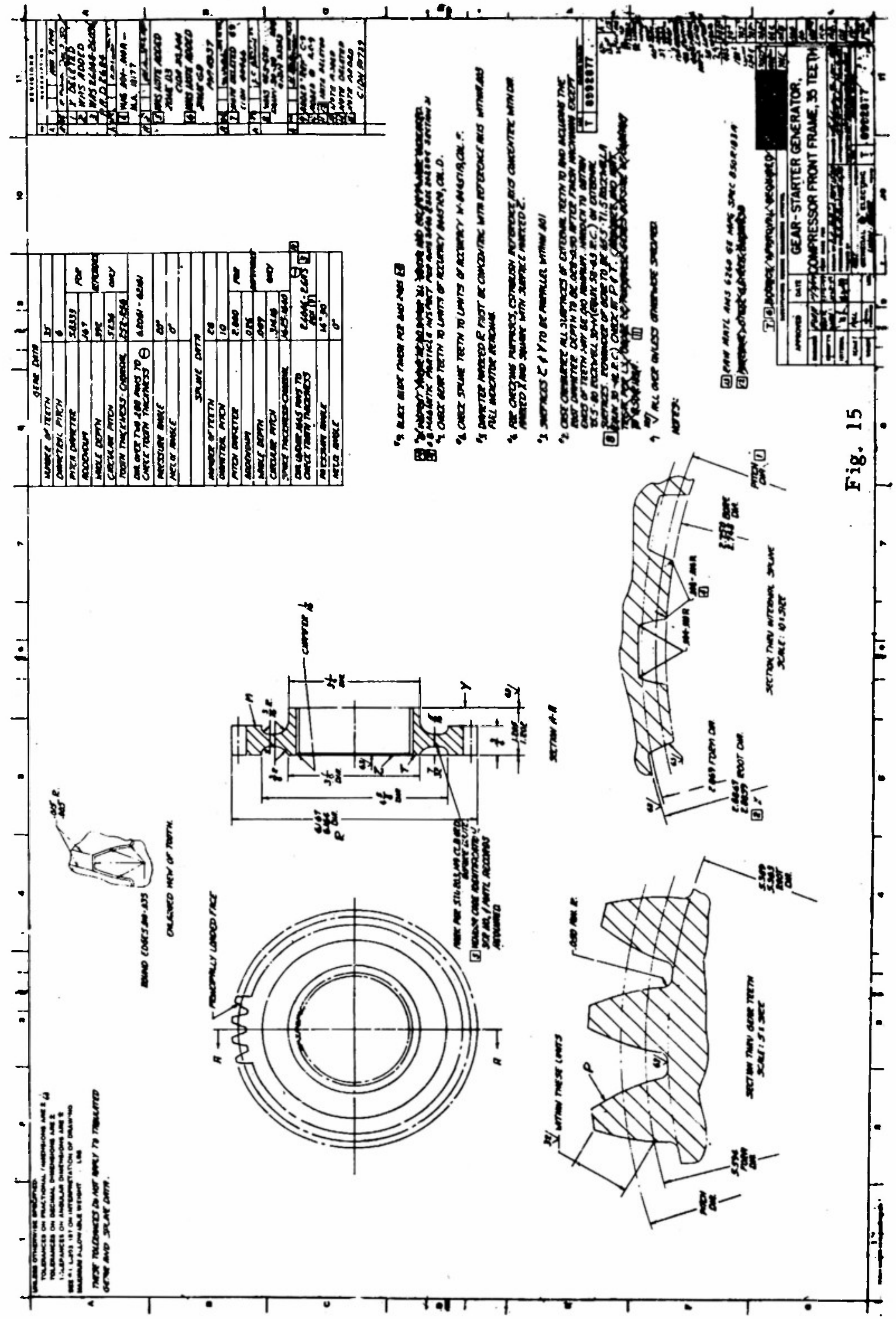


Fig. 15

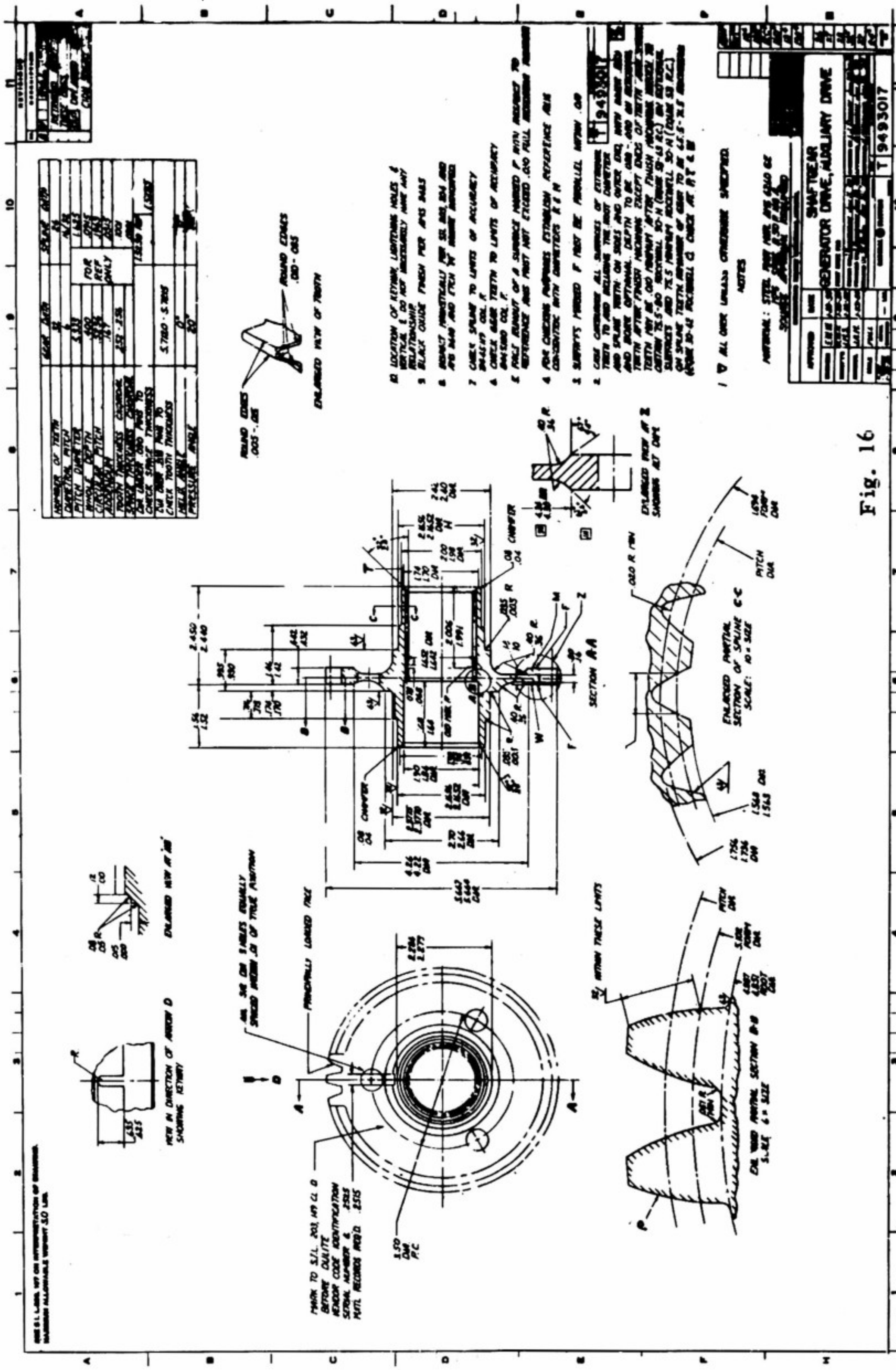


Fig. 16

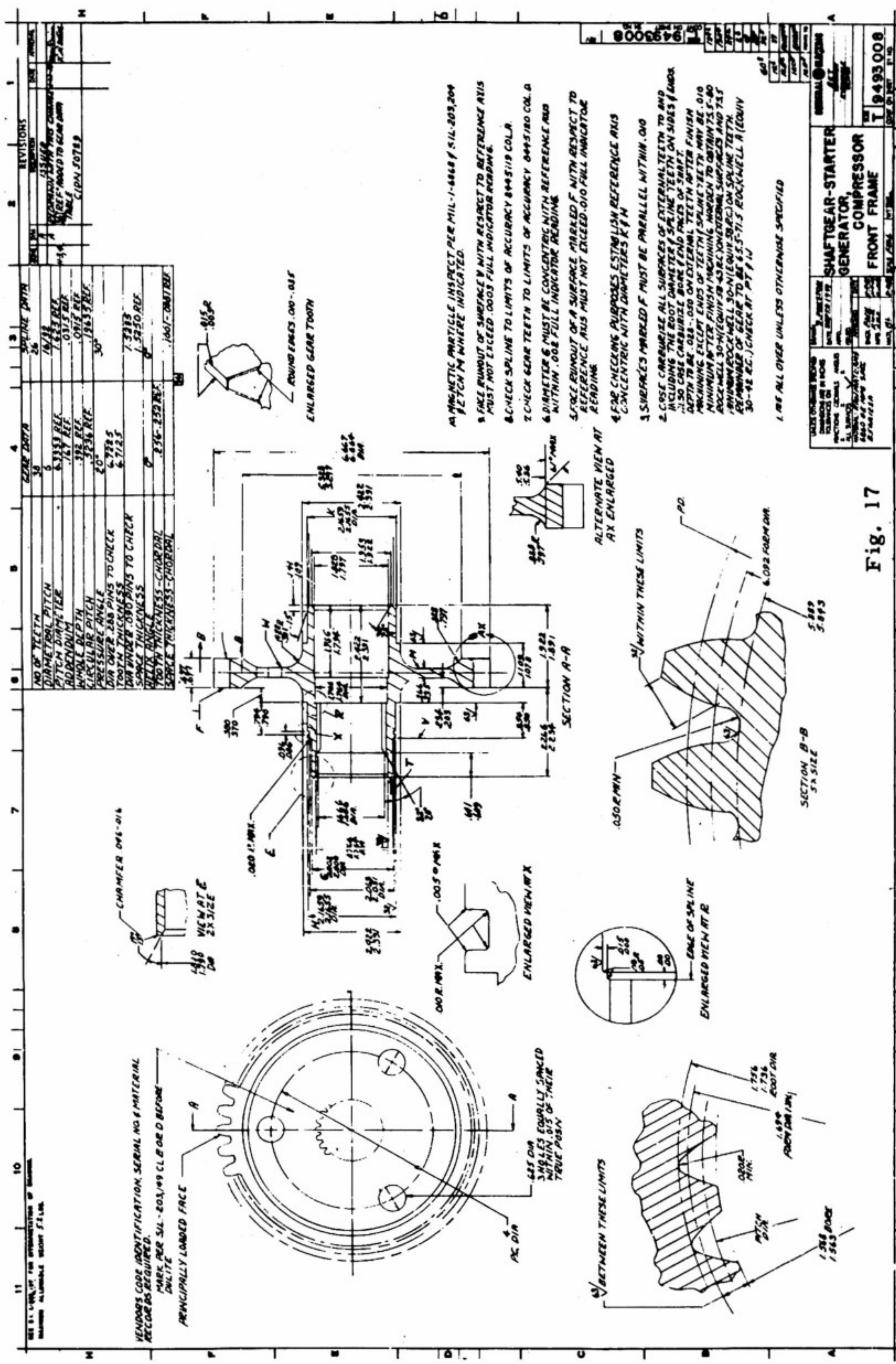

SHAFTGEAR-STARTER GENERATOR, COMPRESSOR FRONT FRAME
9493008

Fig. 17

TABLE 1

Strength and Geometry Requirements of Gears

Dwg. No.	Rated Torque (in. - lb.) Max.	Rated Torque (in. - lb.) Cont.	R.P.M.	Speed Ratio
8992877	17050	3870	7950	1.000
9493008	18500	4200	7320	.921
9493013	6600	1500	7710	.970
9493017	6400	1455	7950	1.000

Dwg. No.	Gear Ratio	Diametral Pitch	Pitch Dia.	No. of Teeth	Min. Face Width	Addendum	Whole Depth	Circular Pitch	Root Dia. (in.)	Outside Dia. (in.)
8992877	1.085	6	5.833	35	.735	.167	.392	.5236	5.389-5.363	6.167-6.164
9493008	1.085	6	6.333	38	.677	.167	.392	.5236	5.899-5.843	6.667-6.664
9493013	1.032	6	5.500	33	.360	.167	.400	.5236	5.054-5.018	5.834-5.830
9493017	1.032	6	5.333	32	.432	.167	.400	.5236	4.887-4.851	5.667-5.664

Dwg. No.	K - Factor	Hertz Stress (Psi)	Root Stress (Psi) Max.	Root Stress (Psi) Cont.
8992877	645.16	145,085	129.435	29,379
9493008	645.16	145,085	138,419	31,425
9493013	559.55	135,117	109,926	24,983
9493017	559.55	135,117	92,294	20,983

III. MANUFACTURING

Compressor Wheels

The material used in this investigation was melted at the U.S. Steel Corporation, Duquesene Works as Heat No. X-34511. Material from this same heat was used previously to make turbine hub and shaft forgings. Approximately 4000 lb. of 8 in. square billets were shipped directly to the Wyman Gordon Company for processing into heat treated compressor wheel forgings.

Forging and heat treating procedures identical to those used for forging production wheels made of AISI 4340 were followed. The heat treatment consisted of a 1700°F normalize, 1550°F austenitize with an oil quench, and a draw to Brinell hardness. Draw temperatures ranged between 1110°F and 1170°F. A total of 21 forgings was made. This quantity included 5 forgings of the first stage wheel, 3 forgings of the ninth stage wheel, 5 forgings of the tenth stage wheel, 3 forgings of the eleventh stage wheel, and 5 forgings of the twelfth stage wheel. The same die was used to forge the wheels for the tenth and eleventh stages. The size of the forging billet required for the twelfth stage was incorrectly estimated and caused some loss of material.

The various steps in the process of forging a compressor wheel are illustrated in Figs. 19-26, inclusive.

One forging was shipped to the Evendale Plant Laboratory for metallurgical evaluation. The remaining forgings were sent to the Thompson Aircraft Products Company for machining into finished wheels. No unusual machining difficulties were encountered. However, the quantity of wheels machined may have been too small to reveal the effect of boron steel on tool life or other measures of machinability. All wheels received a full inspection. All dimensions of major and critical importance were acceptable and within drawing limits. Three of the machined wheels were sent to the Evendale laboratory for evalvation.

Gears

Approximately 2000 lb. of 4.5. in. round were shipped to the Lynn River Works, General Electric Company, for manufacturing into forged and machined gears. This material also was from Heat No. X-34511.

A forging and heat treating procedure similar to that used for AISI 4340 induction hardened gears was used. The forging slugs were heated uniformly in a furnace to 2100°F. The slugs were upset at a 2 to 1 ratio for proper grain flow. Care was taken not to work the

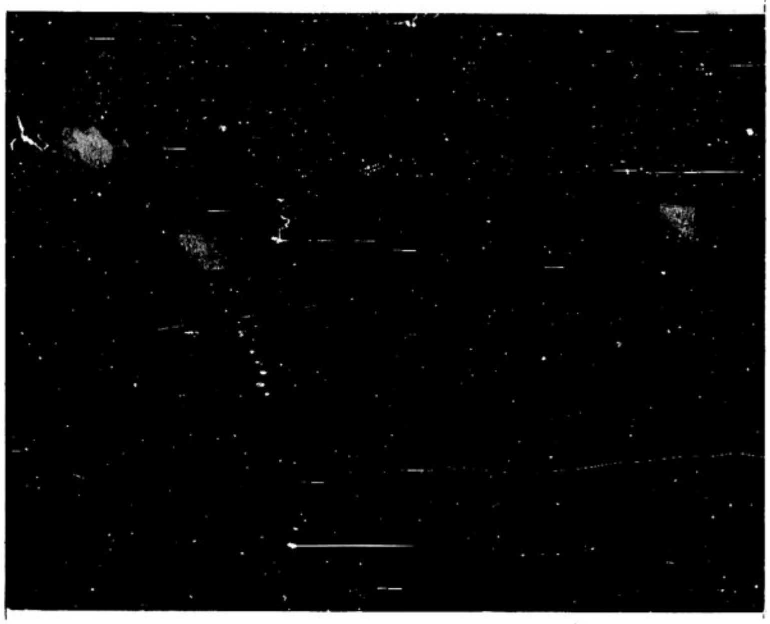


Fig. 19

Heated Multiple Being Transfered From Furnace To Hammer

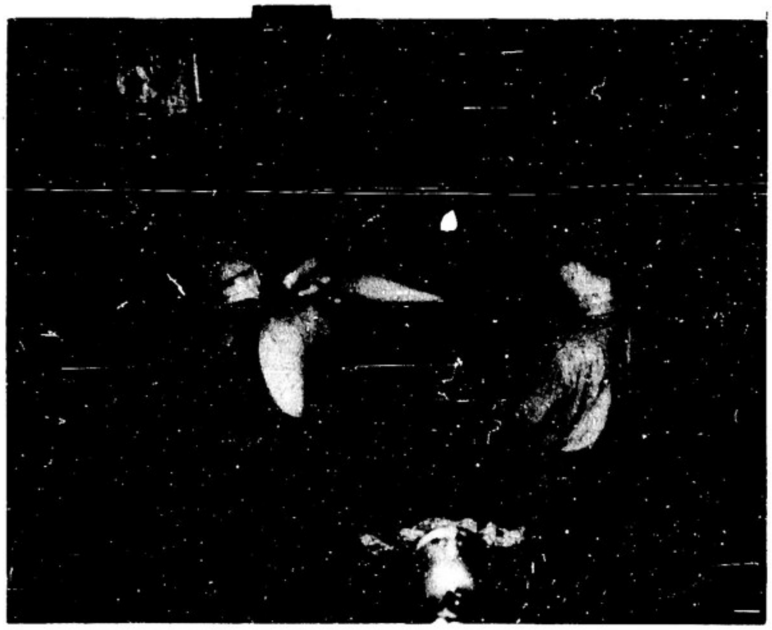


Fig. 20

Blowing Off Scale

Fig. 21
Blocking Operation

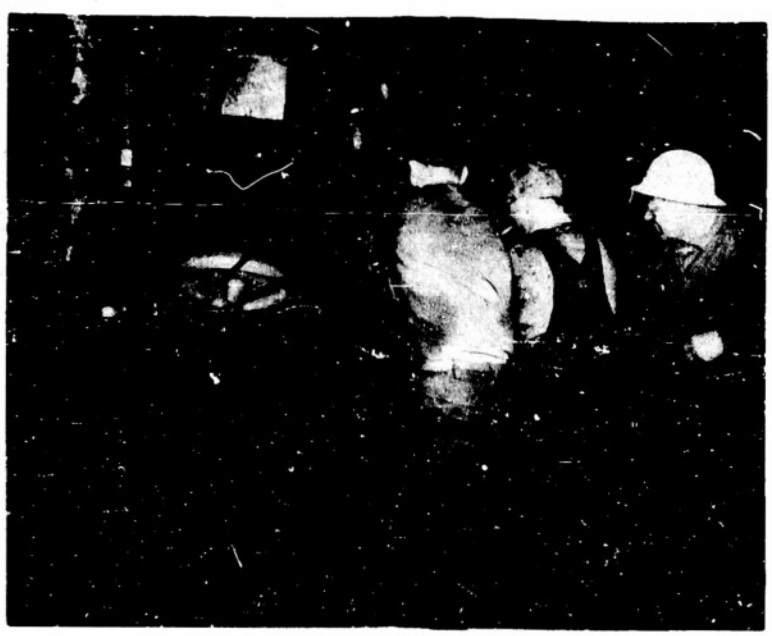


Fig. 22
Removing Forging From Blocking Hammer

Fig. 23
Finishing Operation

Fig. 24
Lifting Forging Prior To Blowing Scale Out Of Die

Fig. 25

Forging Being Transfered From Finish Hammer To Trimmer

Fig. 26

Inspection For Die Closure After Trimming Operation

material below 1800°F. Following forging, each gear was annealed by heating uniformly to 1600°F, holding at heat for 60 minutes per inch of maximum section, but not less than 60 minutes for sections less than one inch thick, and furnace cooling. After rough machining, the gears were heat treated by oil quenching from 1575°F, and tempering at 1100°F. This treatment produced a hardness of 33-38 R_c. The gears were next finish machined and then the gear teeth were induction hardened followed by a stress relief for 4 hours at 400°F. This treatment produced a gear tooth case hardness of 54 R_c. Fig. 27 shows the induction heating coil used.

Gears of this particular type, which are heavily loaded in service, normally are made from AISI9310 material, a carburizing grade of steel containing 3.00-3.50% Ni, 1.00-1.40% Cr, .08-.15% Mo, .08-.13% C. Gear teeth are carburized to produce a case hardness of 58-63 R_c and the core hardness is maintained at 33-38 R_c (see Figs. 14 through 17). In this instance, 98B40 boron steel was used for these gears in an attempt to obtain satisfactory properties with material having lower strategic alloy content.

Before forging, all material was magnafluxed with O frequency and O severity. The finished gears also were magnafluxed. No cracks were detected.

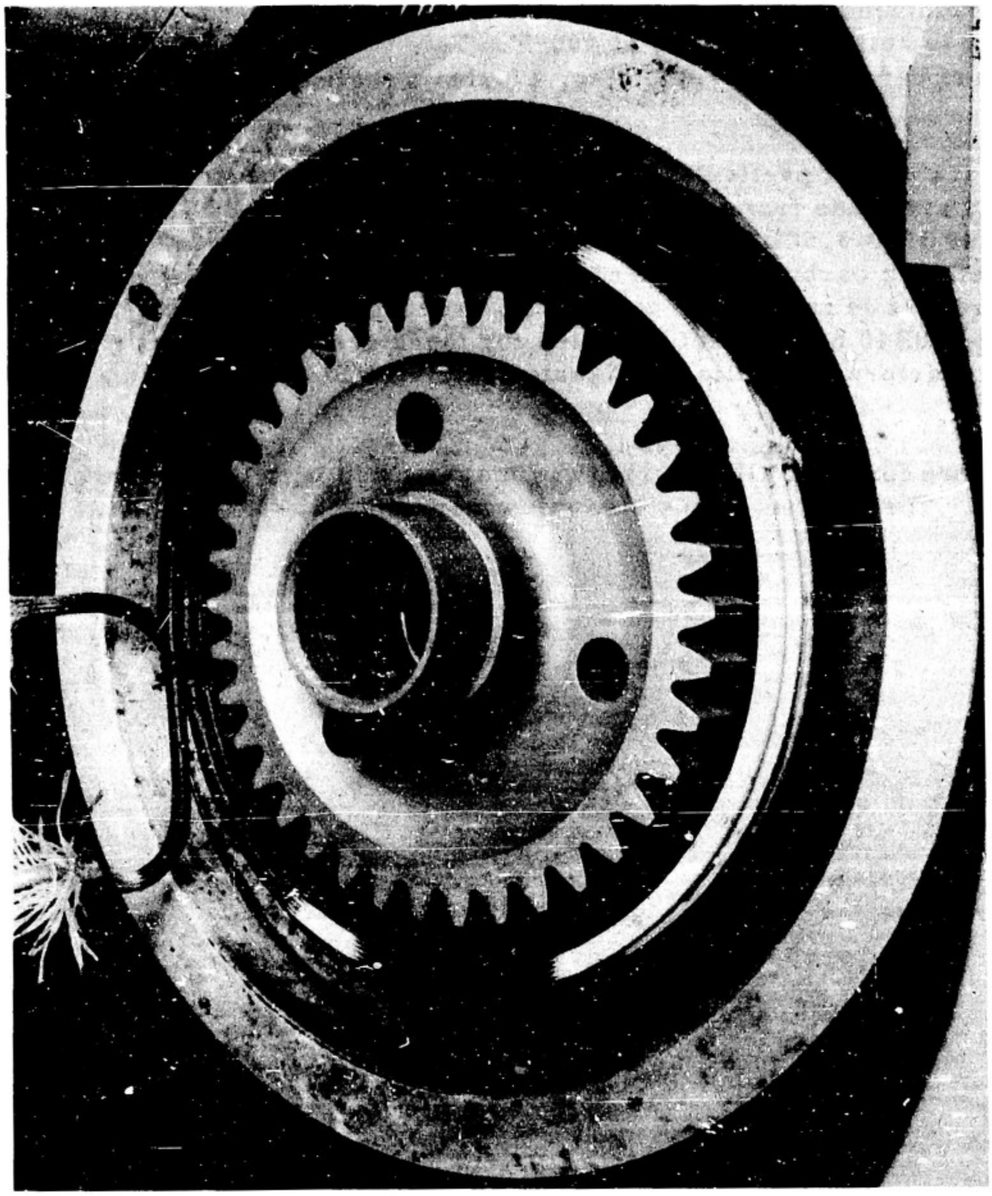


Fig. 27
Induction Heater for Gears

IV. LABORATORY INVESTIGATION AND RESULTS

WYMAN - GORDON LABORATORY. One tenth stage compressor wheel forging was sectioned and its room temperature tensile properties were determined at the Wyman-Gordon Company Laboratory in Worcester, Massachusetts. Tangential specimens from the rim, web, hub, and coupling flange and radial specimens from the web, hub, and coupling flange exhibited uniform tensile properties. Ultimate tensile strength varied from 145,500 psi to 149,000 psi. The average was 146,400 psi. Yield strength values ranging from 129,500 psi to 132,500 psi were found. Average yield strength was 130,700 psi. Elongation values found varied from 13% to 21%. The average was 17.5%. Reduction of area varied from 37.8% to 53.7% and averaged 48.5%. The lowest elongation and reduction of area values are on the same specimen. The second lowest values for these properties are 16% and 43.2%, respectively. When compared to tensile properties obtained by the Evendale Materials Laboratory (which are presented later), the Wyman-Gordon results show sightly higher ductility and lower strength. This is believed due to a slightly lower level of heat treated hardness in the Wyman-Gordon tested forging.

EVENDALE MATERIALS LABORATORY. Three compressor wheels, one each of the first, tenth, and twelfth stages, together with two sets of four gears each were submitted to the Evendale Materials Laboratory for metallurgical evaluation. Results of this investigation are outlined below.

A. Compressor Wheels.

1. Sectioning Procedure

Each wheel was sectioned diametrically to allow for macroetching and hardness survey of a diametral section. The first and tenth stage wheels were finish machined, whereas the twelfth stage wheel was rough machined only. Preliminary hardness checks indicated that the first and tenth stage wheels were in the range 32-35 R_c, but that the twelfth stage wheel had a hardness level of only 26-29 R_c. Since the 32-35 R_c range represented the desired hardness level, it was decided to reheat treat one half of the twelfth stage wheel to the desired hardness level. The heat treatment was carried out as follows:

1575°F, 4 Hrs., Oil quench

1100°F, 9 Hrs., furnace cooled at 50°F/Hr. to 500°F, then air cooled.

The resulting hardness was in the range 34-35 R_c.

From the re-heat treated portion of the twelfth stage wheel were removed tensile, impact and stress-rupture test specimens according to the sketches of Fig. 28.

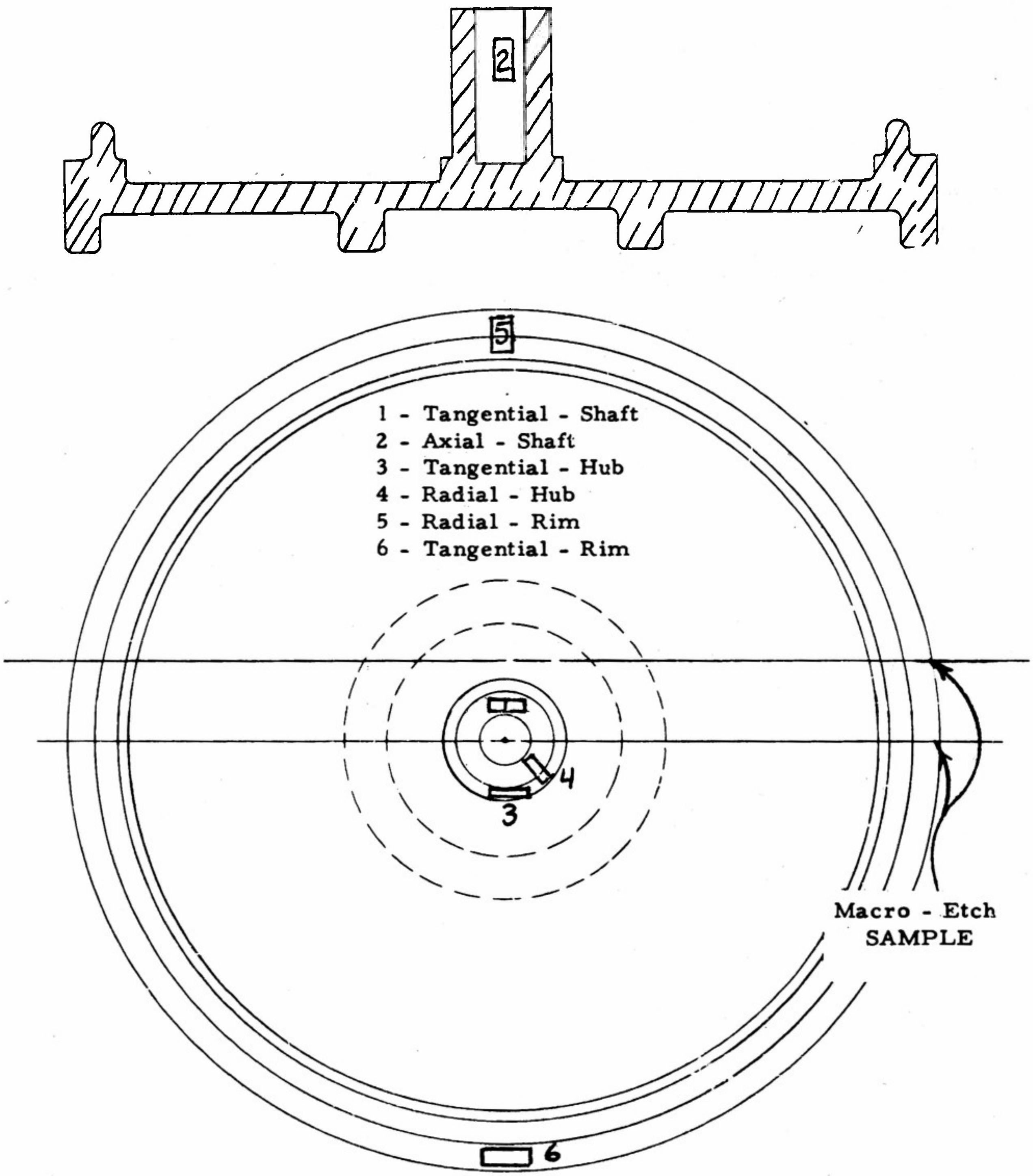


Fig. 28

Twelfth Stage Wheel
Location of Test Bars

Actual mechanical property determinations were made only on the twelfth stage wheel, it being reasoned that the other wheels would exhibit very similar properties.

2. Macrostructure Examination

Figs. 29, 30 and 31 show macroetched half diametral cross sections of each of the three wheels. The grain flow patterns due to forging appear to be essentially normal for the type of forgings involved.

3. Microstructure Examination

A microstructure typical of that found in all three wheels is shown in Fig. 32. This is considered a normal tempered martensitic structure for 98B40 material in the quenched and tempered condition.

4. Hardness Surveys

A hardness survey was taken on a cross sectional piece of the first and tenth stage wheels (actually the specimens previously used in the macrostructure studies). Figs. 33 and 34 are schematic sketches showing location of hardness tests together with Rockwell C hardness values. It is seen that rather uniform hardness values pertained throughout the three cross sections. A cross sectional hardness survey was not made on the re-heat treated 12th stage half wheel inasmuch as each individual test specimen cut from this half wheel was hardness tested, thus effecting a thorough hardness survey throughout the part. The hardness of these test specimens averaged 34-35 R_c.

5. Tensile Properties

In Table 2 are listed tensile properties of specimens cut from the twelfth stage wheel and in Fig. 35 these results are plotted as curves showing the effect of test temperature on tensile properties.

The results show that this wheel was heat treated to a higher strength level than the 98 B40 turbine hub and shaft forgings and similar 4340 parts previously reported in WADCTR 53-60. Reduction of area and elongation results are similar to those previously reported.

An unusually high ratio of yield strength to tensile strength was found. Test bars from this forging had a ratio of .859 at room temperature, .682 at 600°F, and .714 at 750°F. These compare favorably with room temperature ratios on the previously reported 98B40 and 4340 of .775 and .785, respectively.

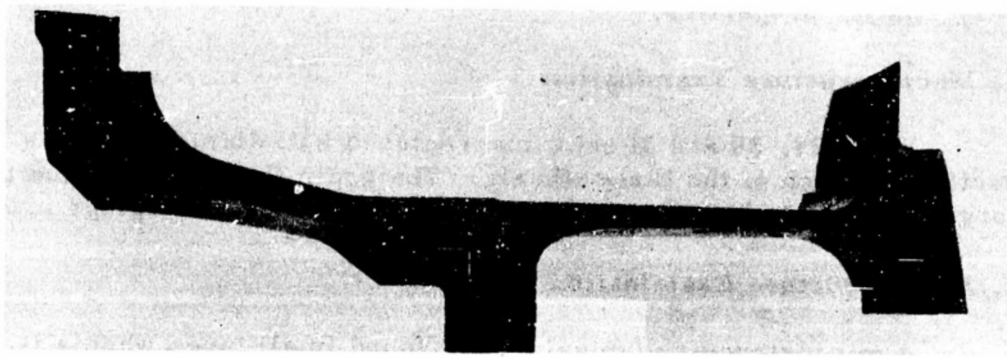


Fig. 29

Macroetch of Half Diametral Section of First Stage 98B40 Compressor Wheel
Etchant: 1:1 HCl, 185°F

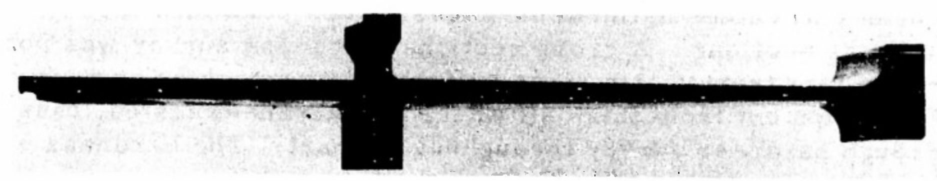


Fig. 30

Macroetch of Half Diametral Section of Tenth Stage 98B40 Compressor Wheel
Etchant: 1:1 HCl, 185°F

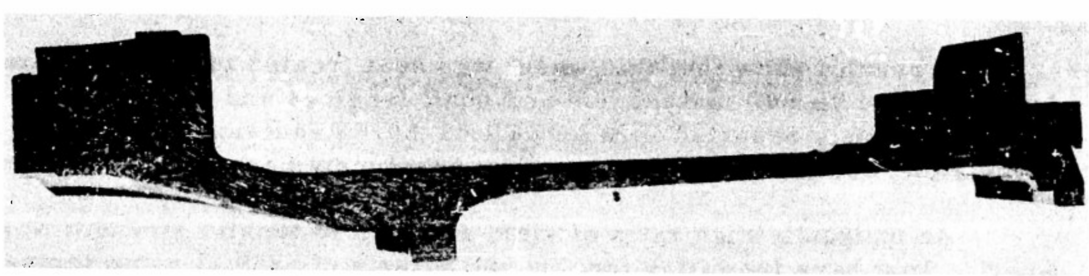


Fig. 31

Macroetch of Half Diametral Section of Twelfth Stage 98B40 Compressor Wheel

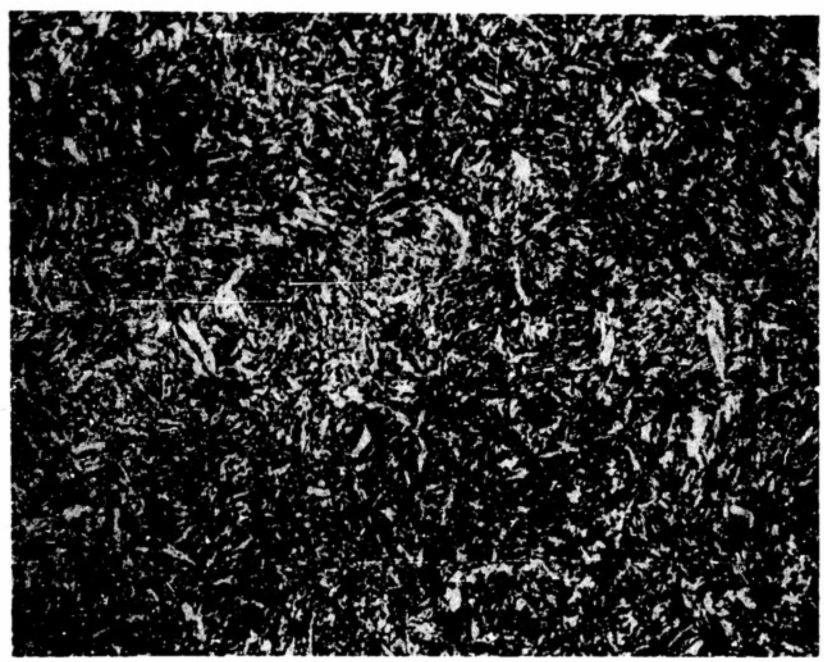


Fig. 32

Microstructure of 98B40 Twelfth Stage Compressor Wheel
Etchant: 2 % Nital Magnification : 500 X

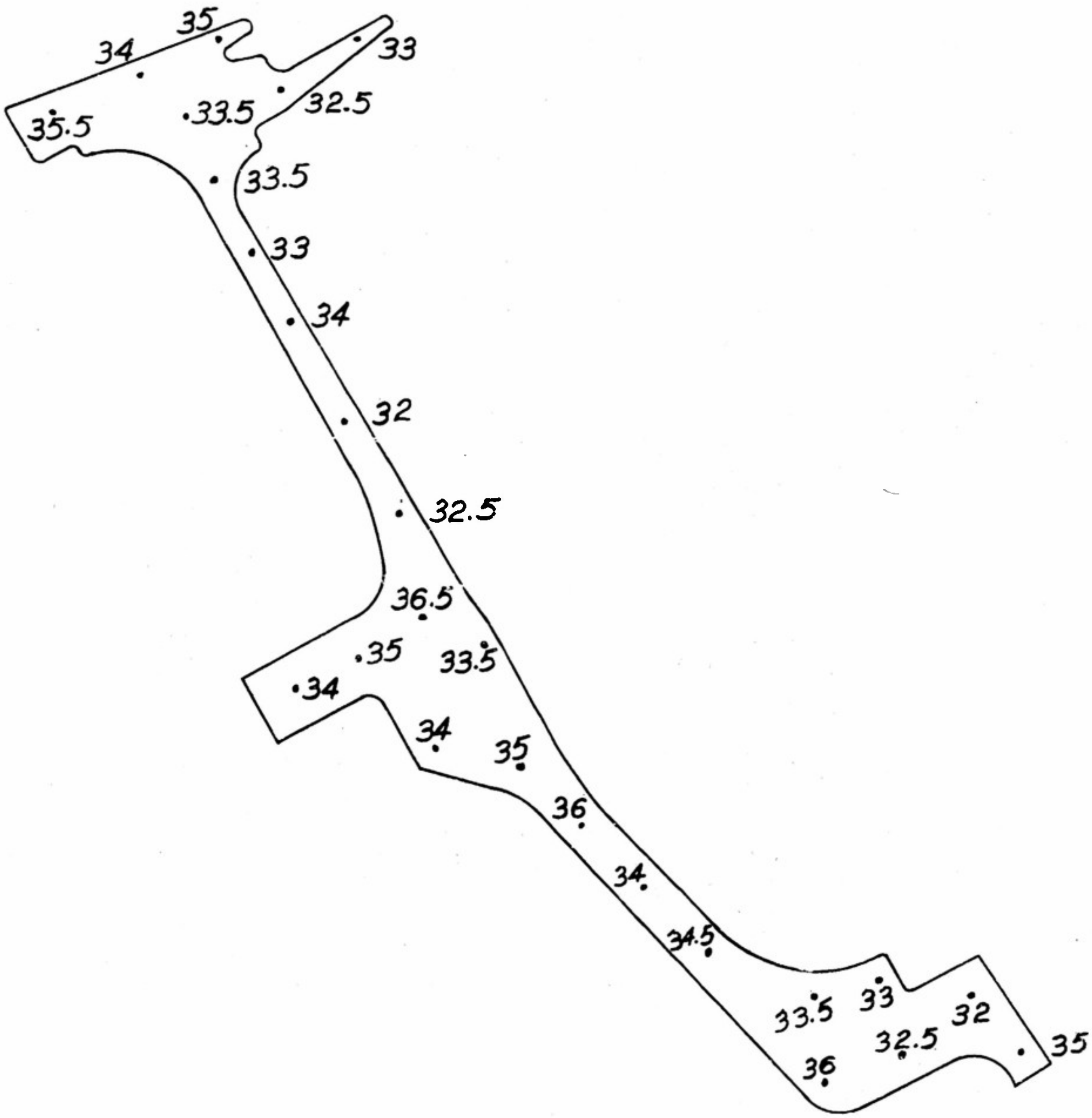


Fig. 33

1st Stage Wheel
Rc Hardness Survey

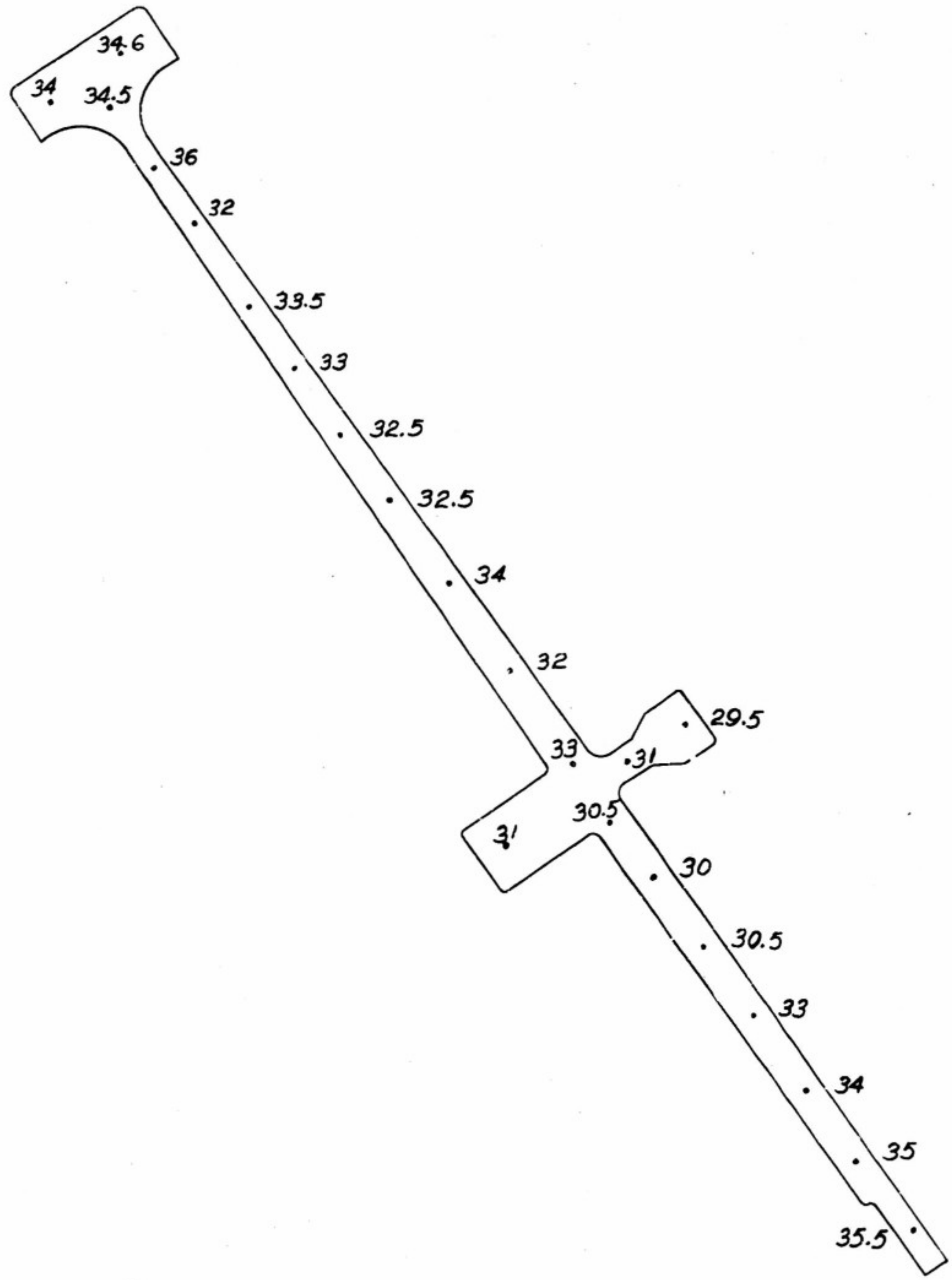


Fig. 34

10th Stage Wheel
Rc Hardness Survey

TABLE 2

Effect of Temperature on Physical Properties of 98B40 Twelfth Stage J-47 Compressor Wheel Forging

Sample Location	Temperature	Tensile Strength PSI	.02% Yield Strength PSI	Elongation % in 2 in.	Reduction of Area, %
axial - shaft	Room	160,600	137,300	17	47.6
axial - shaft	Room	152,000	134,500	16	47.5
axial - shaft	Room	151,000	132,400	16	48
radial - hub	Room	157,800	134,500	17	44.6
radial - rim	Room	160,300	134,600	17	43.3
tangential - shaft	Room	160,700	135,600	14	36.3
tangential - shaft	Room	156,700	134,600	14	32.3
tangential - rim	Room	157,300	135,200	16	36
radial - hub	600°F	144,600	BAD CHART	20	62.6
radial - rim	600°F	147,500	99,400	19	57
tangential - shaft	600°F	148,600	104,100	20	53.8
tangential - hub	600°F	147,000	98,400	21	58.6
tangential - rim	600°F	146,800	100,100	20	57.8
tangential - shaft	750°F	129,200	90,100	19	53.6
tangential - hub	750°F	130,400	95,200	20	57.5
tangential - rim	750°F	130,100	92,700	20	56.1

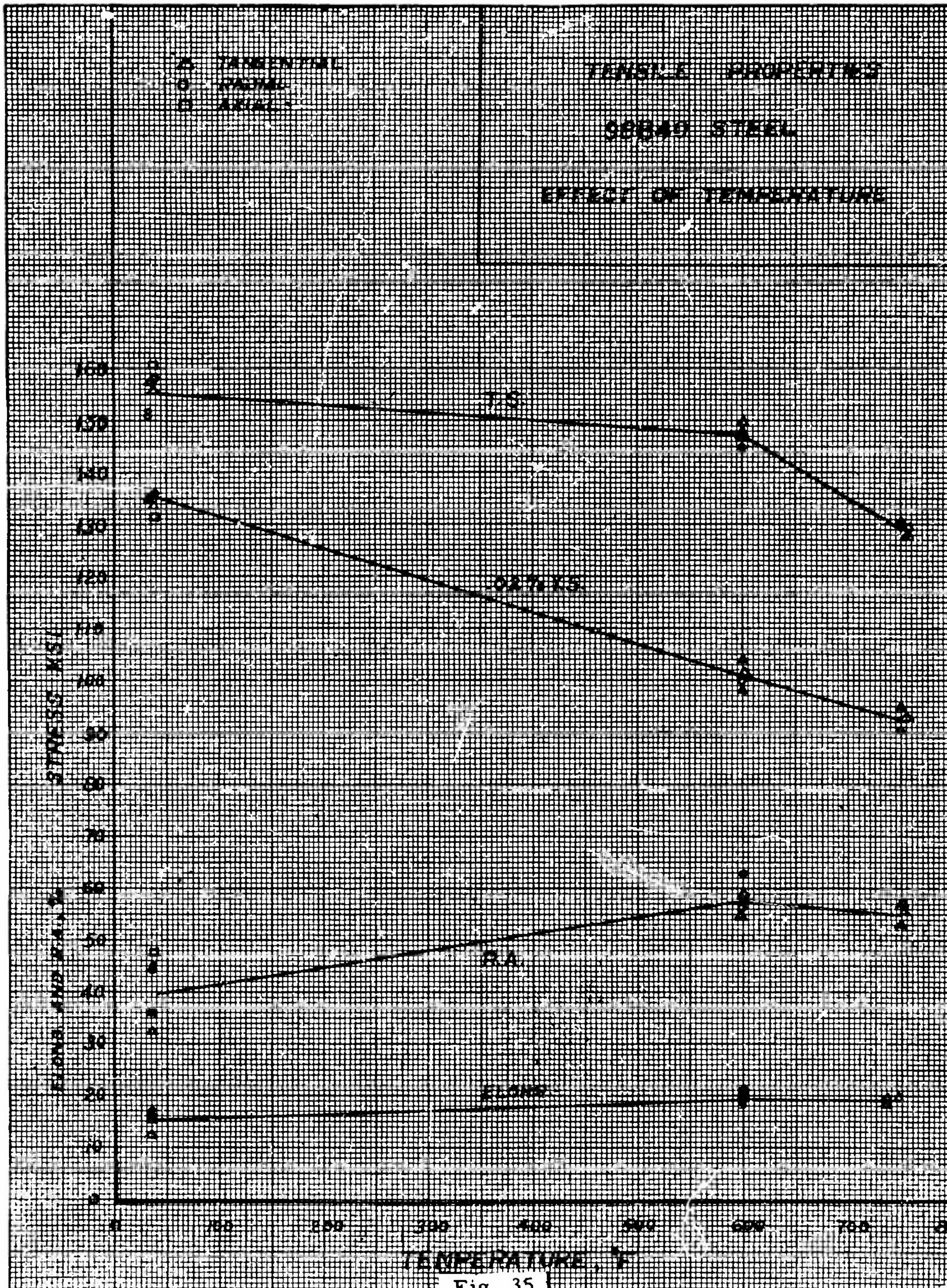

TANGENTIAL
RADIAL
AXIAL
TENSILE PROPERTIES
98B40 STEEL
EFFECT OF TEMPERATURE
T.S.
.02% Y.S.
R.A.
ELONG.
STRESS KSI.
ELONG. AND R.A. %
TEMPERATURE, °F
0
100
200
300
400
500
600
700
800
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

Fig. 35

6. Impact Properties

Keyhole Charpy impact test results on bars from the 98B40 twelfth stage wheel are given in Table 3. These results are compared in Fig. 36 with earlier results on the 98B40 turbine hub and shaft and on 4340. It is seen that the present impact strengths are higher than the previously reported values for 98B40 although they still are lower than the impact strengths of 4340. The advantage held by 4340 decreases with decrease in temperature.

The impact transition temperature based upon 80% of room temperature impact strength is -70°F for both test series on 98B40 and -80°F for 4340. Based upon per cent fibrous fracture, the impact transition temperature for this 98B40 is closer to +60°F previously reported for 4340 than to -20°F previously reported for 98B40. Note that the + 65°F fibrous fracture plot represents six test bars while the -65°F plot represents two test bars. The impact strength of 98B40 is believed to be adequate throughout the temperature range investigated.

7. Rupture Properties

Rupture properties of specimens from the twelfth stage wheel are listed in Table 4 and plotted with a master rupture curve for 98B40 in Fig. 37. It is seen that the results agree closely. 98B40 is notch ductile, at least at the temperatures and stresses investigated.

B. Gears

1. Sectioning Procedure

One set of gears was sectioned diametrically for macroexamination. The second set was sectioned in a plane perpendicular to the axis and surface ground for a macroexamination and hardness survey.

2. Macrostructure Examination

Fig. 38 shows macroetched half diametral cross-sections of each of the four gears. The induction hardening patterns on the teeth and splines reveal that all the required areas are hardened to a sufficient depth.

Fig. 39 shows macroetched cross-sections in a plane perpendicular to the axis of each of the four gears. The hardened zones include the entire tooth areas and extended well beyond the tooth radii.

TABLE 3

Charpy Keyhole Impact Properties of 98B40 Twelfth Stage J-47 Compressor Wheel Forging

Sample Location	Temperature °F	Foot Pounds	% Fibrous
tangential - shaft	600	—	100
tangential - shaft	600	23	100
radial - hub	600	31.5	100
radial - hub	600	27	100
tangential - shaft	+65	22	100
radial - hub	+65	27	100
radial - hub	+65	25	100
axial - shaft	+65	30	100
axial - shaft	+65	27	100
tangential - shaft	+65	25	100
tangential - shaft	-65	20	80
tangential - shaft	-65	22	80

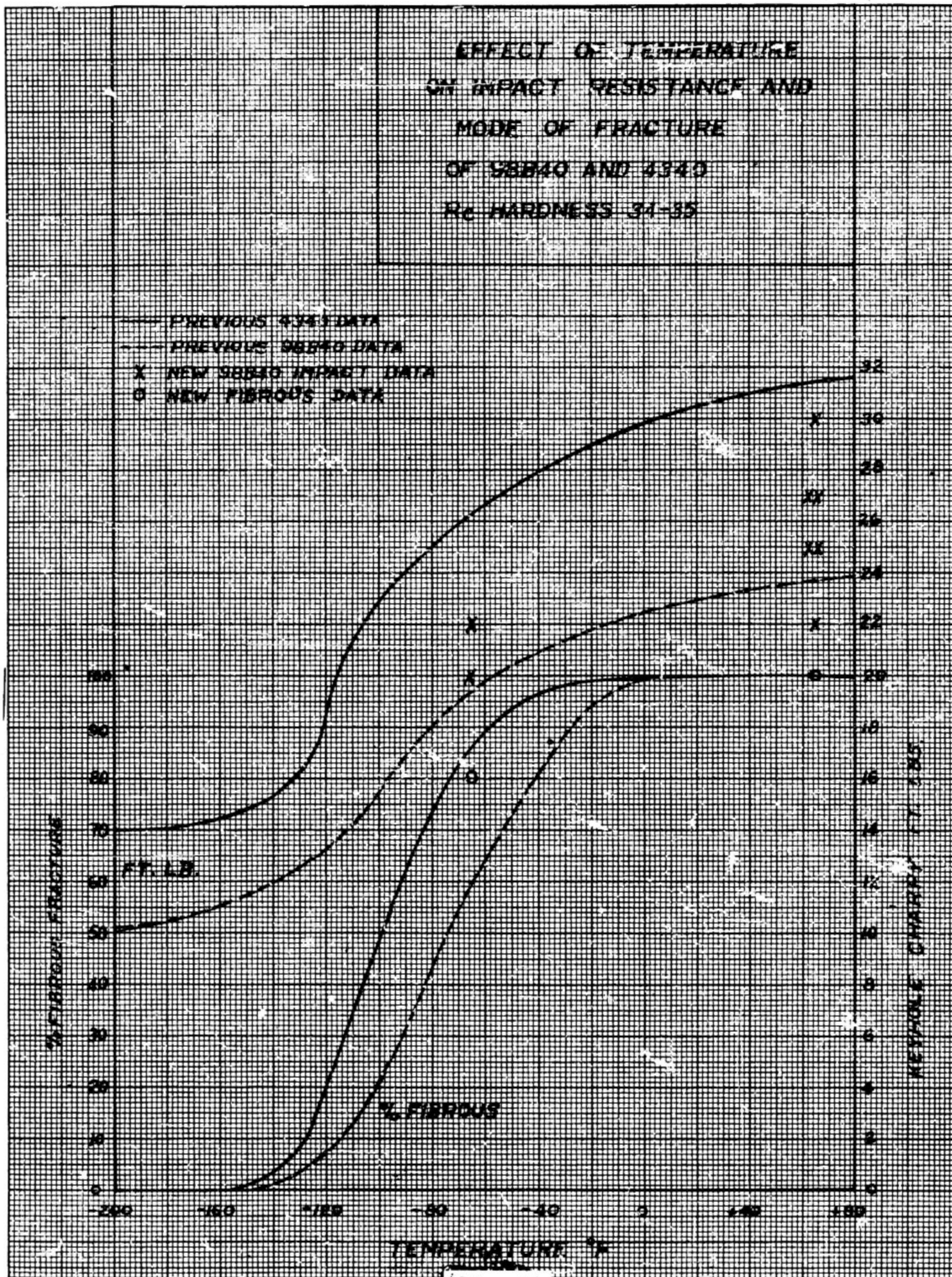

EFFECT OF TEMPERATURE
ON IMPACT RESISTANCE AND
MODE OF FRACTURE
OF 98B40 AND 4340
Rc HARDNESS 31-35
PREVIOUS 4340 DATA
PREVIOUS 98B40 DATA
X NEW 98B40 IMPACT DATA
O NEW FIBROUS DATA
FT. LB.
% FIBROUS
% FIBROUS FRACTURE
KEYHOLE CHARPY FT. LBS.
TEMPERATURE °F

Fig. 36

TABLE 4

Rupture Properties of 98B40 Twelfth Stage J-47 Compressor Wheel Forging

Sample Location	Test Temperature °F	Stress PSI	Hours	% Elong.	Parameter	Condition
radial - hub	1000	50,000	62	-	31.8	notched
radial - rim	1000	50,000	18	31	31.05	smooth
tangential - shaft	1100	20,000	56	30	34.1	smooth
tangential - shaft	1100	20,000	41	33	33.95	smooth
tangential - hub	1100	20,000	73	-	34.3	notched
tangential - hub	1100	20,000	58	-	34.15	notched

Note: The parameter is $T(20 + \log t)10^{-3}$ where T is absolute temperature °Fahrenheit and t is time in hours.

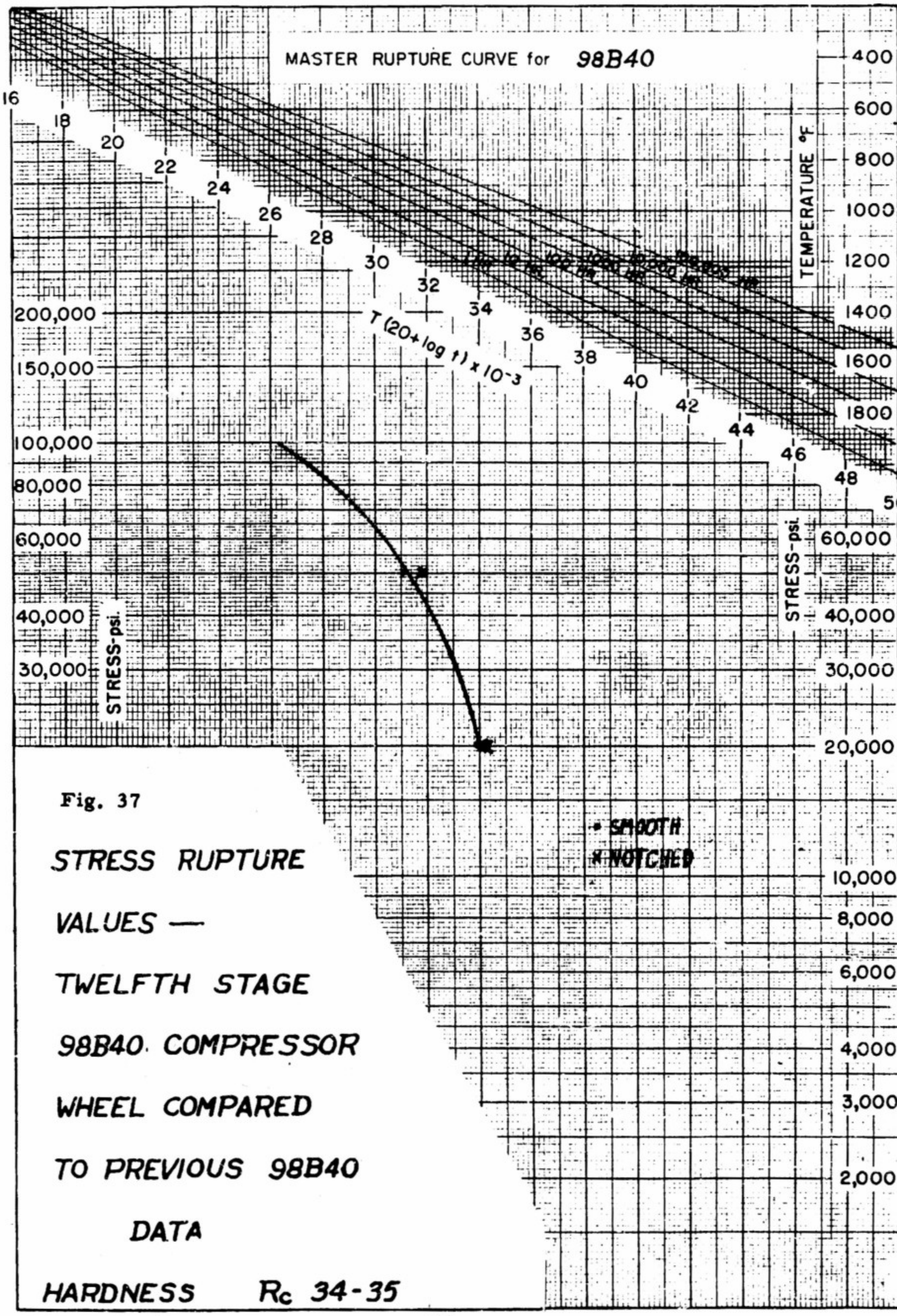
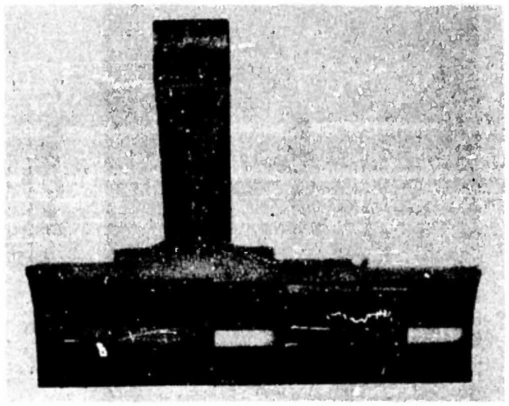


Fig. 37

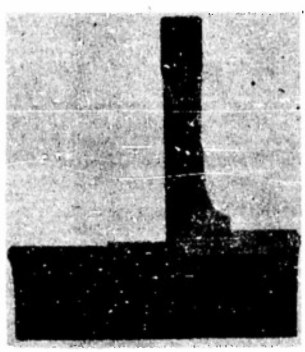
STRESS RUPTURE VALUES — TWELFTH STAGE 98B40 COMPRESSOR WHEEL COMPARED TO PREVIOUS 98B40 DATA

HARDNESS R_c 34-35

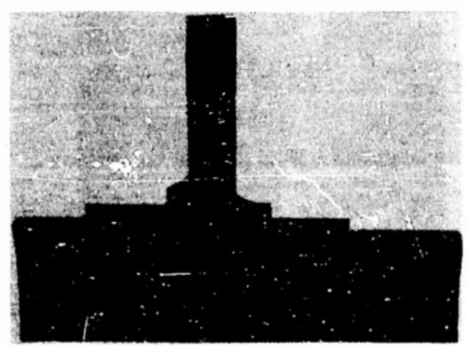


Gear 9493008

Gear 8992877



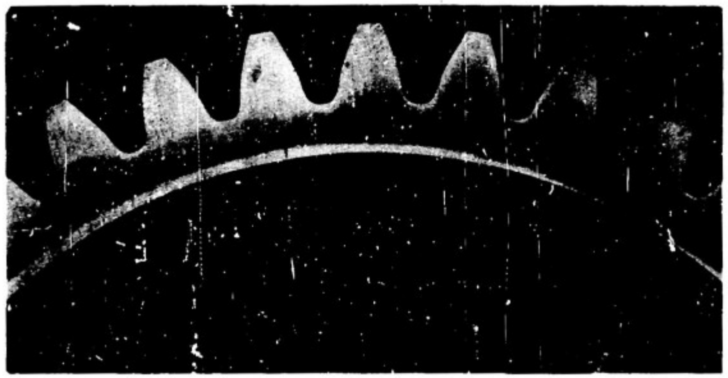
Gear 9493013



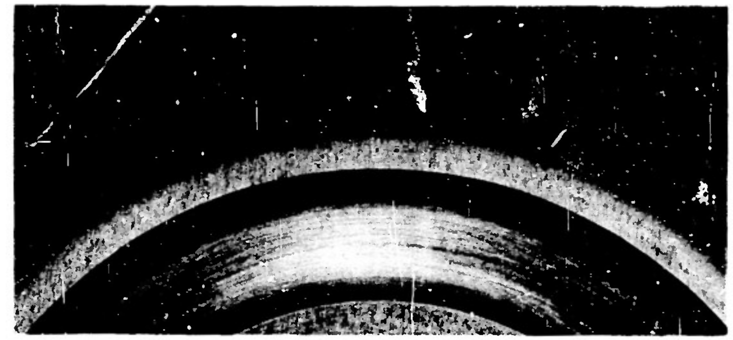
Gear 9493017

Fig. 38

Macroetched Half Diametral Section of Four 98B40 Gears Showing Induction Hardening Patterns.
Etchant : 1:1 HCl, 185°F



Gear 9493008



Gear 8992877

Gear 9493013

Gear 9493017

Fig. 39

Marcroetched Sections of Four 98B40 Gears Showing Induction Hardening Patterns
Etchant: 1:1 HCl, 185°F

3. Microstructure Examination

A microstructure typical of that found in the core of all gears except 8992877 is shown in Fig. 40. This is an essentially normal structure for 98B40 quenched and tempered to a hardness of 34-35 R_c. Gear 8992877 apparently was not hardened in the core and contained some blocky ferrite in its structure.

A typical microstructure found in the case of all the gears is shown in Fig. 41. The lighter areas are lightly etching martensite. The remaining darker structure is acicular martensite.

4. Hardness Surveys

Average hardness of the induction hardened teeth on all four gears is 54 R_c. Average hardness of the core on all gears except 8992877 is 35 R_c. Gear 8992877 obviously was not hardened throughout since it has a core hardness of 10-18 R_c. It has an average case hardness of 54 R_c showing that the teeth were induction hardened.

Rockwell 30 N hardness traverses on the induction hardened teeth are recorded in Table 5. It is seen that sufficient hardening depth resulted from the treatments given and that no soft spots exist in the case or in the case-core transition zone.

A case hardness of 58-63 R_c normally is expected when gears of this design have been carburized. These induction hardened gears have only a 54 R_c average case hardness because the 0.40% carbon content is inadequate to result in a uniformly higher hardness. If this hardness level is essential, a higher carbon content steel could be induction hardened to produce a case hardness of 58-63 R_c. 98B40 is suitable for medium hard through hardening gears. The resultant average core hardness of 35 R_c in three gears is within the normally expected range of 33-38 R_c. As mentioned above, gear 8992877 was not hardened throughout and consequently has a lower core hardness than the other three gears. A similar gear is on engine test and the results of this test will indicate the overall effect of this lower core hardness.

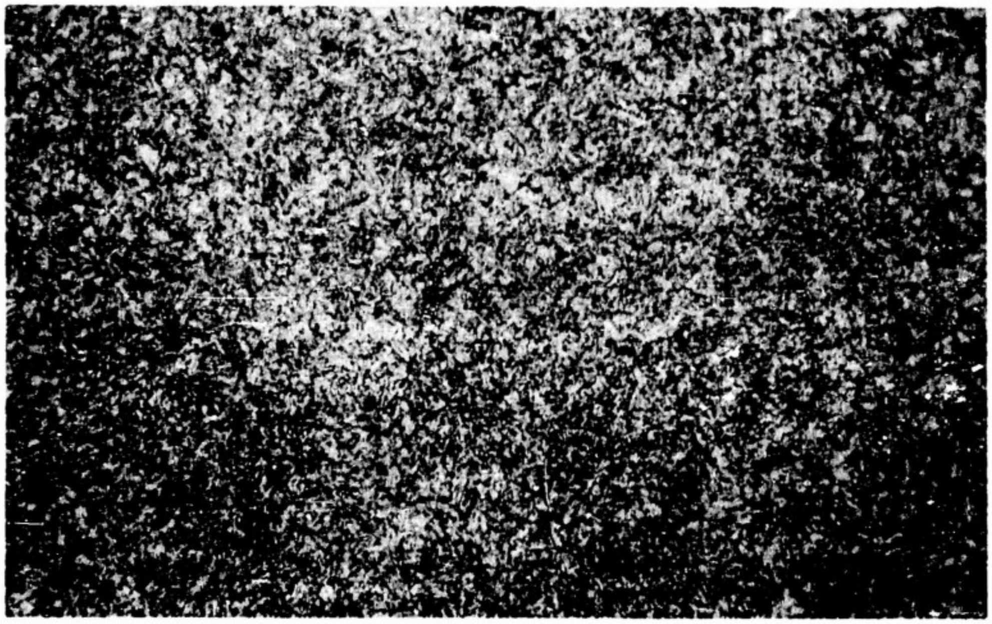


Fig. 40

Microstructure of core in induction hardened 98B40 Gear
Etchant: 2% Nital Magnification: 500 X

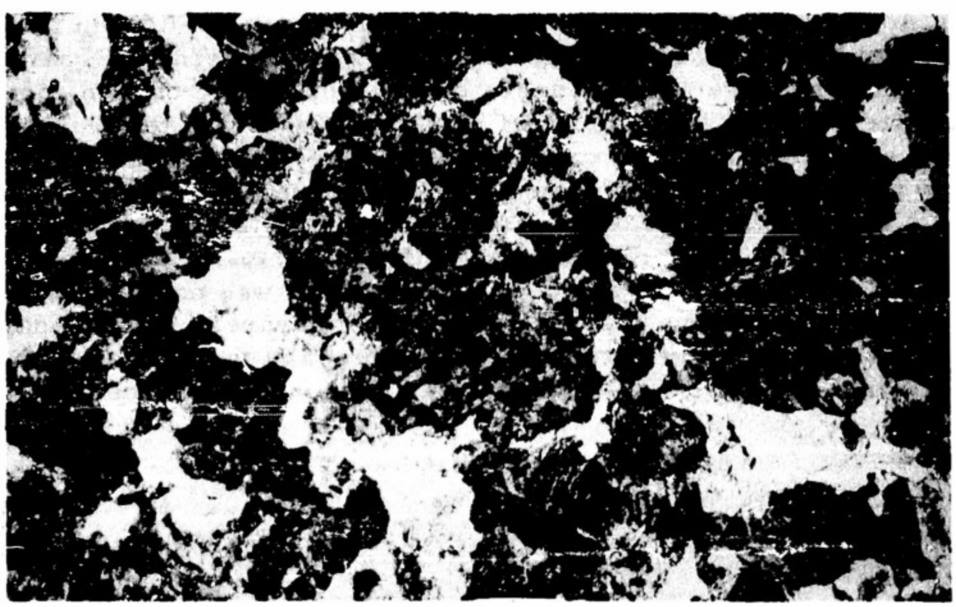


Fig. 41

Microstructure of case in induction hardened 98B40 Gear
Etchant: 2% Nital Magnification: 500 X

TABLE 5

Hardness Pattern On Induction Hardened Gears

16ths Inch from Tooth Edge	Gear 9493008 R_{30N}	Gear 9493008 Converted to R_c	Gear 8992877 R_{30N}	Gear 8992877 Converted to R_c	Gear 9493013 R_{30N}	Gear 9493013 Converted to R_c	Gear 9493017 R_{30N}	Gear 9493017 Converted to R_c
1	69	50.5	72	54	73.5	55.5	73.5	55.5
2	73.5	55.5	75.5	58	72.5	54.5	77	59.5
3	73.5	55.5	70	51.5	71.5	53.5	76.5	59
4	74	56	73	55	75	57	68	49.5
5	72.5	54.5	70.5	52	72.5	54.5	70	51.5
6	73	55	71.5	53.5	72.5	54.5	76.5	59
7	71.5	53.5	70	51.5	71	53	76.5	59
8	69.5	51	67.5	49	65.5	46.5		
9	64	45	59.5	40	51	30.5		
10	51	30.5	45	24	53.5	33.5		
11			34	Below scale				

V. CONCLUSIONS

A. Compressor Wheels

The basic metallurgical properties of 98B40 significant to the J-47 compressor wheels reported herein are comparable to those of 4340. The mechanical properties of 98B40 compressor wheels are essentially equivalent to those of 4340 compressor wheels.

Current manufacturing techniques for forging and machining of 4340 compressor wheels can be applied without modification to 98B40 compressor wheels.

Production use of 98B40 in the subject J-47 compressor wheels appears feasible pending successful completion of engine testing.

B. Gears

The 98B40 steel is satisfactory for medium hard through hardening gears. However, an attempt to substitute an induction hardened 98B40 gear for a case hardened SAE 9310 gear at a hardness level of Rockwell C58-63 was not successful. It can be used if a surface hardness of Rockwell C54 produced by induction hardening is satisfactory. The core hardness is adequate.

Production use of 98B40 in J-47 gear appears feasible pending successful completion of engine testing.